 Name: Solutions

BME154L (Palmeri)

Spring 2011

Exam #2

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 ± 12 V unless otherwise stated.

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

Signature:____________________________________

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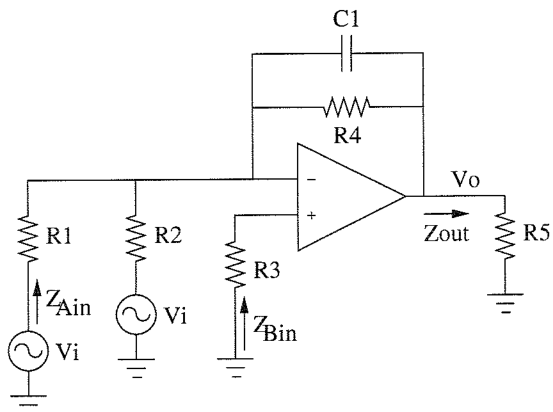
Problem #1 [10 points]

Input/Output Impedance (Revisited)

Impedances can be in terms of Rs and C_1. Please don't answer the 'Why?' questions below with more than 2-3 sentences!!



2 (a) What is the input impedance ($Z_{A_{in}}$), as indicated on the circuit above? R_1

2 (b) What is the input impedance ($Z_{B_{in}}$), as indicated on the circuit above? ∞

2 (c) Which input impedance is more ideal when working with voltage input signals? Why? Z_{Bin}; max. voltage on op amp input terminal

2 (d) What is the output impedance (Z_{out}), as indicated on the circuit above? $\emptyset$

2 (e) What is the ideal output impedance when working with voltage signals? Why?

$\emptyset$; no voltage division on output (i.e., impedance of attached load doesn't affect V_o)

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Problem #2 [30 points]

Cardiovascular Anatomy/Physiology and the ECG Signal

3 (a) Today is Vivek's birthday, but he started "pre-gaming" this weekend while studying for BME154 by putting ECG pads all over his body. One of his friends was helping him with this task, but that friend started handing him pads without gel on them. Vivek threw the pads down in disgust and quickly explained why the pads needed gel to optimize their function. What was Vivek's explanation? (It is okay to assume that Vivek was correct.) $\downarrow Z$

2 (b) What is the primary function of the sino-atrial (SA) node in the heart? Pacemaker (self-depolarize ~60bpm)

2 (c) What are the two most important functions of the atrio-ventricular (AV) node in the heart? ① Delay ② Pacemaker Backup

2 (d) The QRS complex represents what electrical process in the heart? Ventricular Depolarization

3 (e) Myocardial ischemia can cause what changes to the QRS complex of the heart? Why do these changes occur? ① Widening ② ↓ Amplitude

5 (f) Put the following pieces of the electrical system of the heart in order of depolarization for a heart beat, starting just before the P wave would be present on an ECG trace:

- Bundle of His
- Purkinje Fibers
- AV Node
- SA Node
- Left/Right Bundle Branch

SA Node → AV Node → Bundle of His → L/R B.B. → Purkinje Fibers

(g) High blood pressure can cause the ventricles of the heart to hypertrophy. Please answer the following with 1-2 sentences.

2 (a) What is hypertrophy and why does this occur? ↑ muscle mass to overcome high pressures

3 (b) How might ventricular hypertrophy be evident on an ECG trace? ↑ amplitude

2 (c) What does ventricular hypertrophy do to cardiac stroke volume in the extreme case (think of the over-developed bicep from lecture)? ↓ S.V. (reduced ventricular volume)

(h) Having ECG lead wires of equal impedance reduces noise for certain capacitive coupling problems, but not others. In the context of capacitive coupling to wires and the body, (1) explain which scenario benefits from equal impedance lead wires (and why), and (2) what the ideal absolute impedance of the wires should be in each case relative to the input impedance of the ECG monitor they are attached to.

3 ① Cap. coupling to wires → reduce differential voltage to ECG monitor

3 ② As small as possible.

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Problem #3 [40 points]

Analog ↔ Digital

A 4-bit successive approximation ADC is calibrated to convert voltages ranging from 5 - 20 V.

4 (a) How many discrete voltage levels can be represented by a 4-bit number? $2^4 = 16$

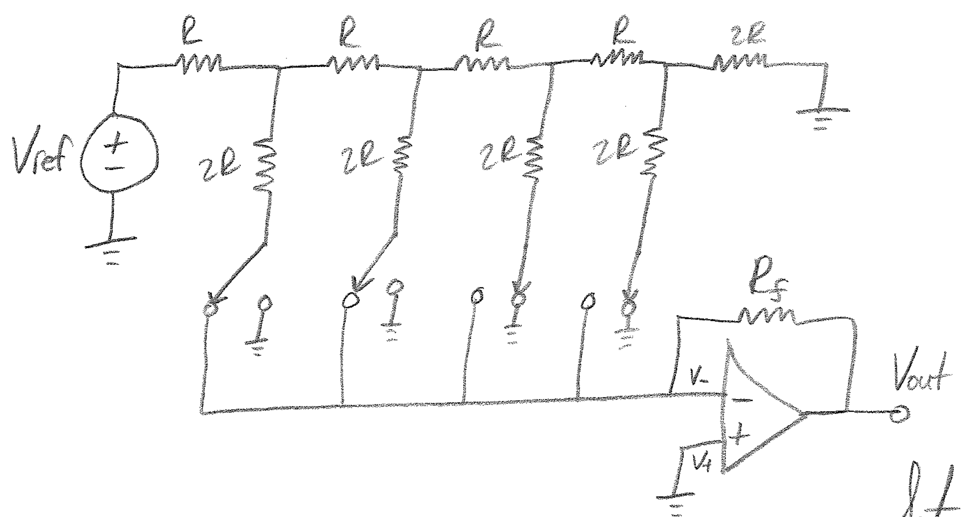
4 (b) What is the voltage of the least significant bit for this ADC? $\frac{(20-5)V}{2^4-1} = 1V$

5 (c) What is the highest signal-to-noise ratio (SNR) that this ADC can accurately convert without wasting bits on sampling noise? $20\log_{10}\left(\frac{15V}{1V}\right) = 23.5\,dB$

2 (d) How many voltage comparisons are made during the successive approximation of the 4-bit number? 4

5 (e) If the input voltage being converted is 17.3V, then solve for the discrete voltages that are compared to the input voltages during this process (list them in order of how they are compared in this ADC). (Show your work for this to get partial credit!) $\underset{(1)\checkmark}{13V} \rightarrow \underset{(1)\checkmark}{17V} \rightarrow \underset{(0)}{19V} \rightarrow \underset{(0)}{18V} \Rightarrow 1100$

20 (f) This ADC is only as good as the DAC that is being used "behind the scenes". Design an R-2R DAC that can be used in this successive approximation ADC.



Set R, R_f + V_{Ref} such that $V_{out} = -V_{ref}\left(\frac{R_f}{R}\right)\left(\frac{15}{16}\right)$.

Add 5V DC offset w/ inv. summer after Vout, OR add new DC "R" branch attached to V- (current always flowing w/o switch).

No need for LPF stage since discrete comparisons are being made.

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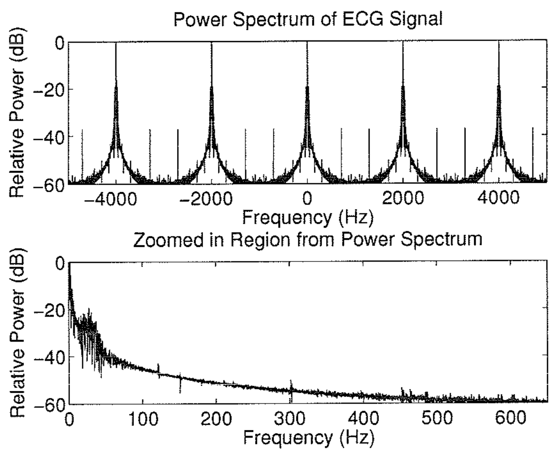
Problem #4 [20 points]

More Analog ↔ Digital

Sarah's twenty-first birthday is this week, and the anticipation has caused her resting heart rate to be a bit high (90 bpm). Just to make sure everything is okay, she hooks herself up to an ECG monitor, and because she heard Vivek yelling the day before, she gets a "clean" signal with an SNR of 40 dB. She decides to save her signal digitally, and samples it at XX kHz with a 16-bit ADC. The power spectrum associated with the sampled signal is shown below.



5 (a) Based on the power spectrum above, what sampling rate ('XX') was used in the ADC? 2000 Hz

2 (b) What was the approximate Nyquist sampling rate for this signal? How did you determine this? 100-160 Hz (< -40 dB considered noise)

2 (c) Sarah's friends go to Radio Shack buy her some op amps and resistors for the task of building a DAC using a scaled resistor summing amplifier to convert her saved ECG signal back to analog. While thrilled with her birthday gifts, she is disappointed that they didn't buy her any capacitors. What would she use a capacitor (or capacitors) to build, and why is that a necessary part of the DAC process? LPF to smooth out discrete transitions

3 (d) Design what is needed after the summing amplifier to complete her DAC and restore the original, analog ECG signal. (Be sure to follow the constraints imposed by the power spectrum above!) LPF w/ $W_c \sim 300 \times 2\pi$ rad/s; 2° would be nice

4 (e) How many discrete digital signal levels can be represented with a 16-bit binary number? Given the specified SNR of the ECG signal (40 dB), are bits being "wasted" sampling noise in this scenario? What would be the "ideal" bit depth for this SNR? 40 dB → 100 levels; 7 bits more appropriate

(f) Given a 90 bpm heart rate, if you were using a JK flip-flop-based counter (like we covered in lecture and the problem sets) to count the number of beats in the ECG over a 1 minute period, then how many JK flip flops would you need? 16 bits → 16

7 bits → 7