BME154L - Exam #2

Name: Solutions

82.5 ± 12

BME154L (Palmeri)

Spring 2010

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.

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

Signature: Solutions

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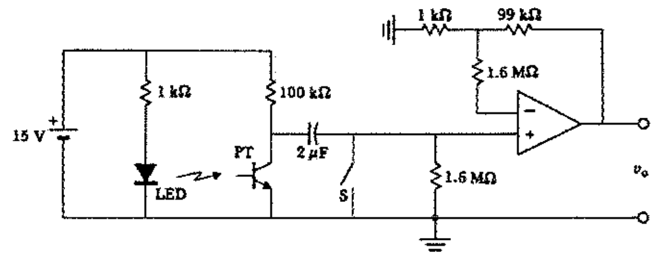
Problem #1 ~~10~~ 15 points

12.7±2.7



Above is a photodetection circuit for a photoplethysmograph...

(a) Briefly describe:

1. The purpose of a photoplethysmograph,
2. The physical principles underlying its function, including the relationship between the power emitted from the LED and the power detected by the phototransistor (PT).

(b) What is the purpose of the 2 μF capacitor in the circuit?

(c) What is the purpose of the op amp in the circuit?

a) 1. Measure HR based on changes in blood volume through a peripheral vessel (artery).

2. Blood attenuates light: in systole the vessel expands b/c its elasticity, leading to greater blood amounts in the light propagation path, leading to greater attenuation of the light.

$$\underbrace{P_o = P_D e^{-\alpha L}}_{\text{exp. decay}}$$ L changes w/ cardiac cycle

b) Part of a passive HPF to remove DC signal & just "see" perturbations.

c) Non-inverting amplifier of HPF'd signal.

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11.5 ± 3.3

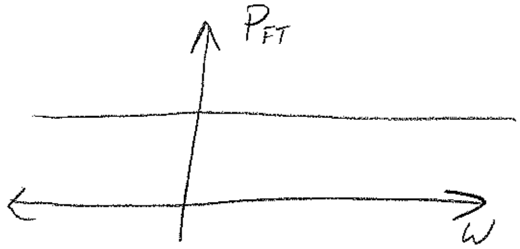
Problem #2 15 points

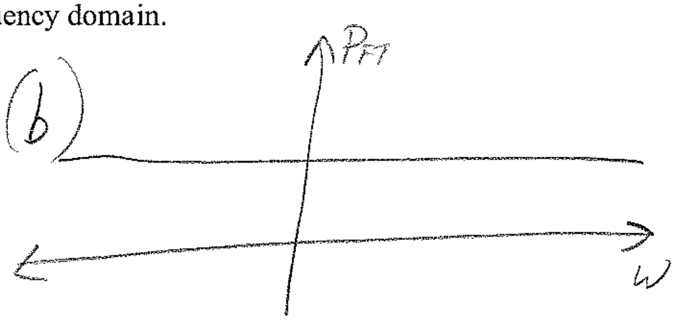
(a) Sketch the frequency power spectrum for a delta function.

(b) Sketch the frequency power spectrum for white noise.

(c) Compare/contrast these two power spectra; is there a conflict here? Why / why not?

(d) The sliding window averager can be implemented as a convolution operation between your signal and a RECT function, where the width of the RECT is a function of the number of samples in your averaging window. Based on this knowledge, a sliding window averager behaves like what type of filter? Justify your answer using the convolution property in the frequency domain.

a) 

(b) 

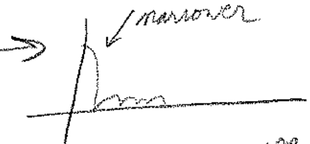
c) Same power spectra; difference is that white noise has random phase, while $\delta(t)$ has a FT w/ a constant phase of 0.

d) Sliding window averager $\rightarrow$ LPF

Limiting cases: 1 sample $\rightarrow \delta(t) \xrightarrow{FT} 1$ Multiply signal × FT in f domain signal

X samples $\rightarrow rect(x) \xrightarrow{FT}$ sinc signal w/ atten. high f

2X samples $\rightarrow rect(2x) \xrightarrow{FT}$ narrower



even greater atten. of high f

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9.1±1.6

Problem #3 10 points

(a) ~~Why is digital data transmission more robust than analog data transmission?~~

(b) ~~Why are checksums used when transmitting/receiving data?~~

(c) A data transmission line has a throughput of 1 Mbit/s. A doctor wants to remotely monitor respiratory rate using tidal volumes ($\approx$ 500 mL) from an intubation tube using a pneumotachometer. The default temporal sampling rate on the pneumotachometer is 100 kHz, but with 32-bit precision per sample, the bandwidth of the transmission line will be exceeded.

1. What does a pneumotachometer directly measure, and how is that useful in the content of measuring tidal volumes?
2. What can be done to reduce the amount of data that is transmitted without compromising the ability to accurately report respiratory rate.

(a) * Less susceptible to noise/corruption
* Error correction
* Encryption + authentication

(b) Error correction; validate integrity of Rx data.

(c) 1. Pneumotach → air flow measured via ΔP; integrate air flow through time to get volumes using ideal gas laws

2. * Downsample (alot!); resp. rate ≈ 20 Hz, 100 kHz is overkill!!
* Peak detect/correlate on Tx; only send resp. rate data
* Reduce bit depth

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6.6±2.8

Problem #4 10 points

A clinician is using thermodilution methods to measure the cardiac output for a patient; unfortunately the clinician is a bit sloppy and has an error of ±10% on the estimated bolus volume injected and a ± 20% error on the initial temperature of the bolus after rapid injection. What are the maximum errors associated with the calculated flow rates associated with these two measurement errors?

$$F = \frac{\Delta \text{ bolus energy}}{\Delta \text{ blood energy}}$$

errors in this term

$$Q = \underset{\pm 10\%}{V_i}\, \underset{\pm 20\%}{\Delta T_i}\, \rho_i c_i$$

$$Q_{min} = (0.9\,V_i)(0.8\,\Delta T_i)\,\rho_i c_i = 0.72\,Q_{True}$$

$$Q_{max} = (1.1\,V_i)(1.2\,\Delta T_i)\,\rho_i c_i = 1.32\,Q_{True}$$

$$\boxed{\begin{aligned} F_{min} &= 0.72\,F_{True} \\ F_{max} &= 1.32\,F_{True} \end{aligned}}$$

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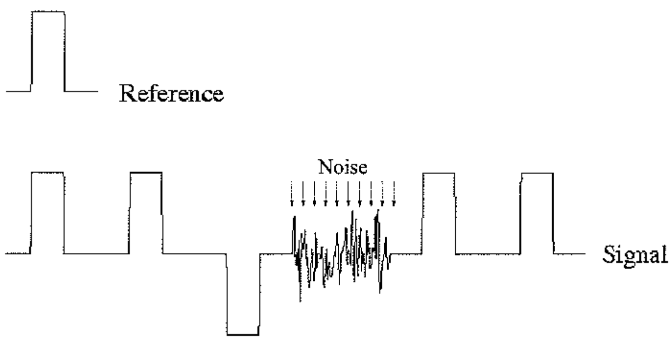
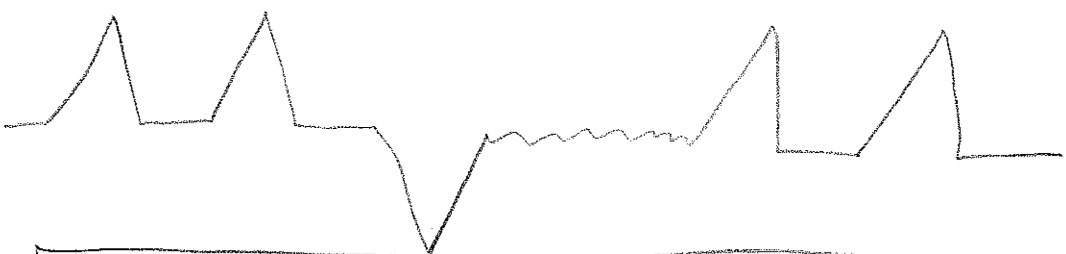
Problem #5 ~~20~~ 15 points



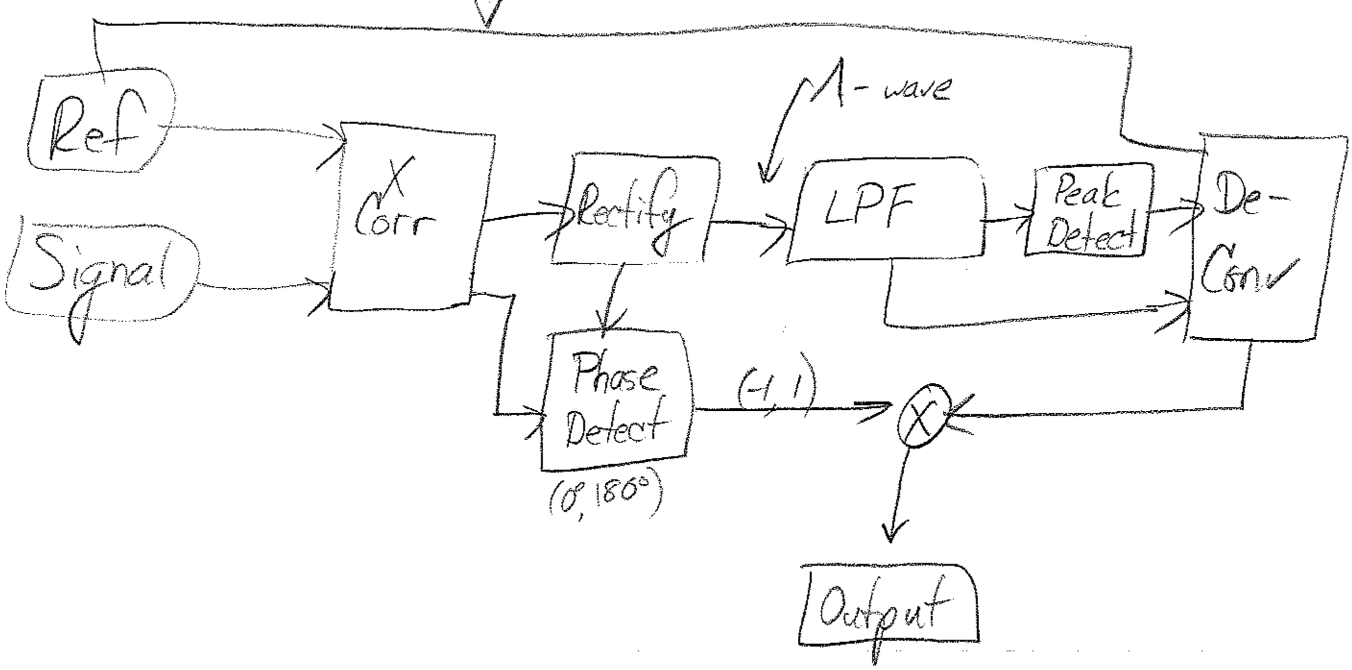
(a) Sketch the cross correlation function between the signal above and the specified reference.

(b) Assuming that the "true" signal includes the periodic RECT waveforms, sketch the block diagram for a device that will remove regions of noise like that shown in the middle of the signal without distorting the RECT waveforms; you can either use the signal, your correlation signal, or both signals as the input to your device. Describe the overall approach that your device is using to identify noise, including your assumptions, and *briefly* describe the function of each block.

(a)



(b)



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30.6 ± 3.8

Problem #6 35 points

(a) Sketch a normal ECG trace with 3 heart beats, including the waveforms associated with atrial depolarization, ventricular depolarization and ventricular repolarization (label these on the sketch).

(b) Sketch the corresponding ECG traces associated with first-, second-, and third-degree heart block (relative to your normal ECG trace) and in 1-2 sentences, describe their characteristic/defining features.

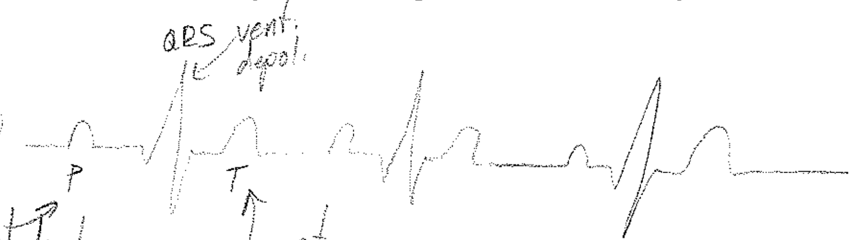
(c) Describe the differences between an asynchronous and a synchronous pacemaker.

(d) When is the worst time during a cardiac cycle to deliver a shocking pulse? Why is this?

(e) Sketch the block diagram for a rate-responsive pacemaker being used to treat third-degree heart block. Your device has several design criteria:

1. Ability to set the resting and maximum heart rate thresholds,
2. Have the heart rate increase linearly as a function of demand,
3. Use one thermistor to use to monitor a physiologic system to determine metabolic demand for your pacemaker. Specify the physiologic system you are monitoring, the location of your measurements in the body, and the output of the circuit that you are utilizing for the rest of your device.

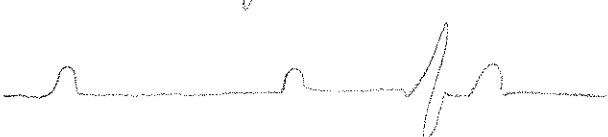
(a)



(b) 1°

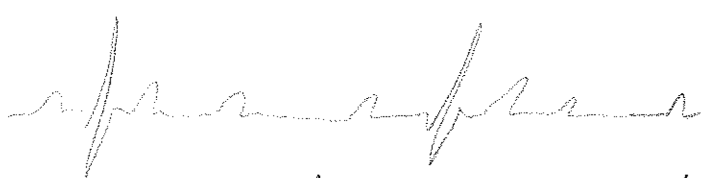
prolonged PR interval; 1:1 P:QRS

2°



e.g. 2:1 P:QRS some atrial beats miss triggering ventricular beats

3°



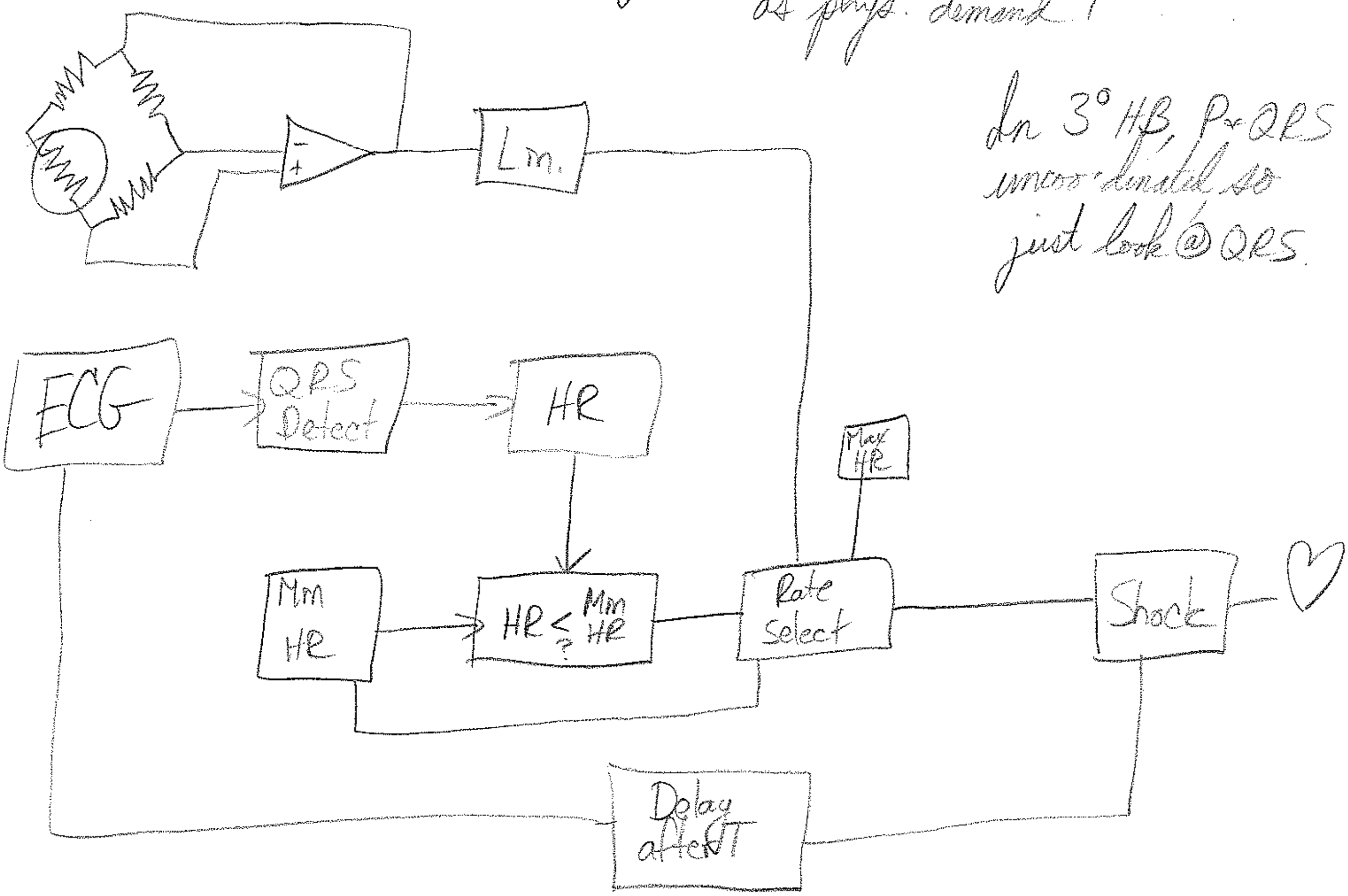
uncorrelated P:QRS

(c) asynchronous → fixed pace rate & no feedback from natural pacing/electrical activity

synchronous → paces when need @ fixed or variable rate

(d) T-wave; partial repol. of vent → can trigger V-fib → bad!

(e) Measure blood temp. in PA using thermal conv. flowmeter; blood cools as phys. demand ↑



In 3° HB, P & QRS uncoordinated so just look @ QRS.

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Problem #7 EXTRA CREDIT (1 point)

Forget to label your axes on one of your plots? Forget to study a certain topic? Well, here's your chance to earn one point back thanks to Duke's recent basketball success.

Duke's fourth national championship came against Butler on Monday; list the schools that Duke has defeated for the first three championships and the years those games were played.

1. Kansas (1991)
2. Michigan (1992)
3. Arizona (2001)
4. Butler (2010)