

Name \_\_\_\_\_

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**BIOENGINEERING**  
**Ph.D. QUALIFYING EXAM**  
Medical Imaging

June 2006

Complete all questions.

Show all work.

**Read the questions carefully, work neatly, and box your answer where appropriate.**

Each problem is worth 25 points.

You have 4 hr to complete the exam.

**Write your name on each page.**

<u>Question</u>	<u>Grade</u>
<u>Bioinstrumentation</u>	<u>/25</u>
<u>Biomaterials</u>	<u>/25</u>
<u>Biomodeling</u>	<u>/25</u>
<b>Concentration:</b>	
<u>Medical Imaging</u>	<u>/25</u>
<b>Total</b>	<b>/100</b>

**Bioinstrumentation**

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1. Design a system suitable for recording a biopotential signal with the following characteristics:

Bandwidth: 0.1 – 1000 Hz

Dynamic range:  $\pm 100$  mV

Assume that you have a 12-bit analog-to-digital converter with an input range of  $\pm 10$  V, and that you wish to digitally record the signal with the highest resolution possible.

A. First, draw a *block diagram* that depicts each stage in your system, and gives the transfer function of each stage.

B. What is the final calibration of your system, in Volts/Volt?

C. What is the final resolution of your system, in Volts/bit?

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D. Draw the amplitude portion of the Bode plot describing your system (from the previous page). Plot the gain in decibels, and indicate the  $-3$  dB pt(s).

E. Give a detailed circuit diagram for the system described on the previous page, showing all component values.

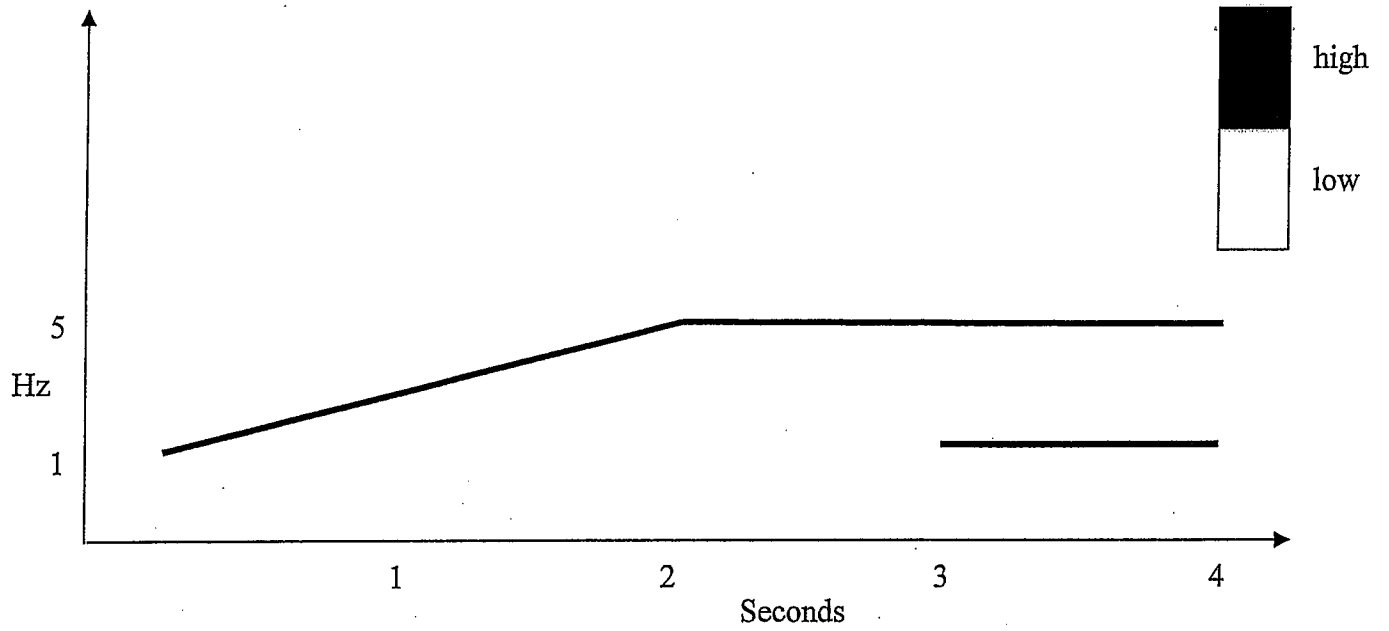
Name \_\_\_\_\_

- F. Assume that the biopotential signal above is a response to a sensory stimulus that has never been recorded before. You wish to characterize this novel signal so that you can report it in the journal *Nature*. How would you empirically determine the signal bandwidth? In particular, how would you distinguish the “unknown” signal from noise in the recording? (Be concise; think before you write.)

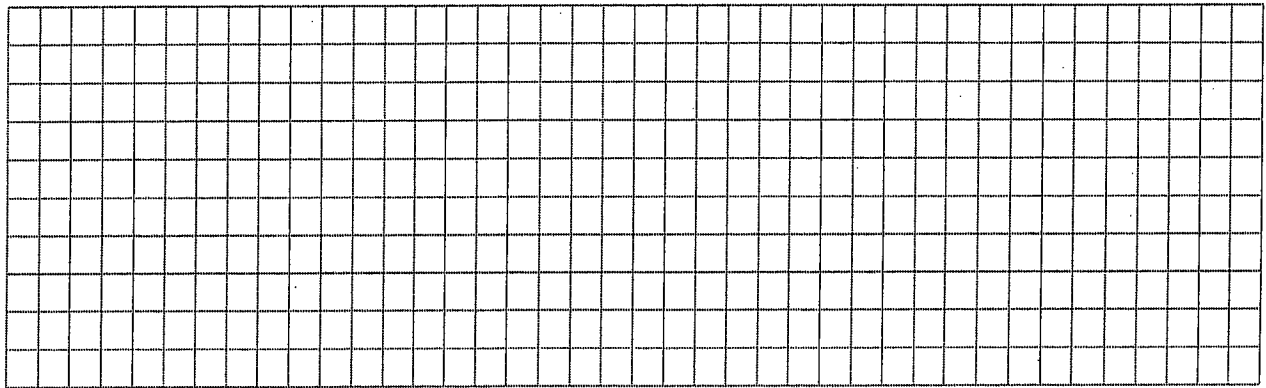
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2. A man is standing in a puddle, which grounds his feet. He reaches overhead to turn on a lamp, but the lamp is faulty and his hand touches a 120 V, 60 Hz AC voltage source. Draw a circuit diagram that describes the currents passing from the source to ground. Indicate the *physical origin* of all impedances in your circuit. State any assumptions, and be as quantitative as possible.

3. Consider the idealized spectrogram below



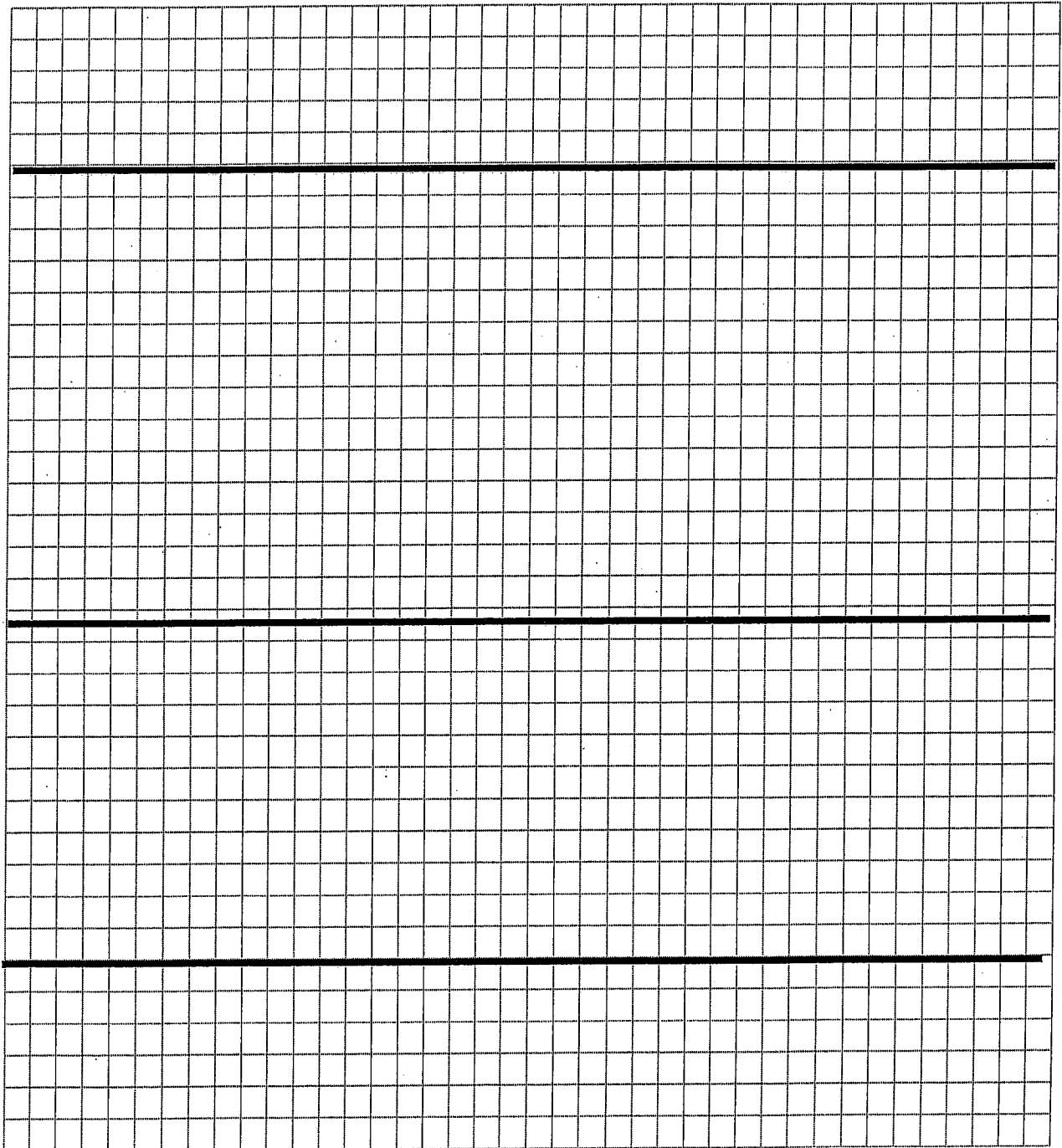
a. On the graph-pad below, draw a time-based voltage waveform from which this spectrogram could have been obtained. Label all axes.



4. Using C, L and R components, create an electric circuit with second order response characteristics.
  - a. Draw and label a circuit diagram with components arranged to provide a second-order system with low-pass characteristics.
  - b. Derive an expression (in terms of R, C and L) for the transfer function of this circuit.
  - c. Choose/determine appropriate component values if the undamped natural frequency of this system is 485 rad/sec and the system is critically damped.
  - d. Determine the magnitude and phase of the transfer function for an 85 Hz sinusoidal signal input.
  - e. Consider the signal you drew in Problem 3 as the input to your circuit. Draw the likely output.

5. Cardiac Mechanics in a Normal Human Heart

- a. On the first line of the graph below sketch both a left and right typical ventricular pressure trace for two successive cardiac cycles.
  - b. On the second line, draw the associated ECG trace
  - c. On the third line, draw the likely heart sounds heard with a stethoscope
- In all cases be sure to label and value both axes!*



- d. For TWO of the signals above (a and b, OR a and c, OR b and c):
  - i. Thoroughly discuss the transducer used in the measurement. Include the source of the signal, the method of transduction, how the transducer is placed etc.
  - ii. For those SAME TWO signals, state and justify the low and/or high-frequency cut-offs you would use for signal conditioning the output of the transducer.



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3. You plan to use an implant made out of material X. Your co-worker, Mr. Slow says that if you do this material X will cause neighboring cells to be lysed by the membrane attack complex.
  - i. What is the membrane attack complex?

- ii. Do you believe your co-worker? Explain why or why not.

Name \_\_\_\_\_

4. Dr. Glass needs to insert a rod in the body. He needs it to be soft while it is being inserted and needs it to be hard 1 hour after it is inserted. NITINOL is not an option for this. What type of material should he use, metal, polymer or ceramic? Explain the material property that will make this possible and how it will work in this case. (Hint: encrypted in this question is a helpful hint.)

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5. Design an **in vitro** experiment to determine if material Y is biocompatible. You must use a standard biocompatibility test. Explain your experimental design in **great** detail. Include sections on: A) how you will know from your results if material Y is biocompatible or not, B) the advantages of the method you chose and C) the disadvantages of your method.

**Biomodeling**

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A linear population model relates the input random variable  $x$  to the output random variable  $y$  in the equation  $y = bx + u$ .  $u$  is a random error term uncorrelated with  $x$  and has moments  $E(u) = 0$ ,  $\text{var}(u) = \sigma^2$ . A random sample model of the population model has the form  $y_i = \hat{b} x_i + e_i$  for  $i = 1, 2 \dots n$  samples and  $e_i$  is a sample estimate of  $u_i$ .

1. Derive an expression for  $b$  such that  $b$  minimizes the variance of  $u$  in the population model.

2. Derive an expression for  $\hat{b}$  such that  $\hat{b}$  minimizes the sum of the squared  $e_i$  in the random sample model.

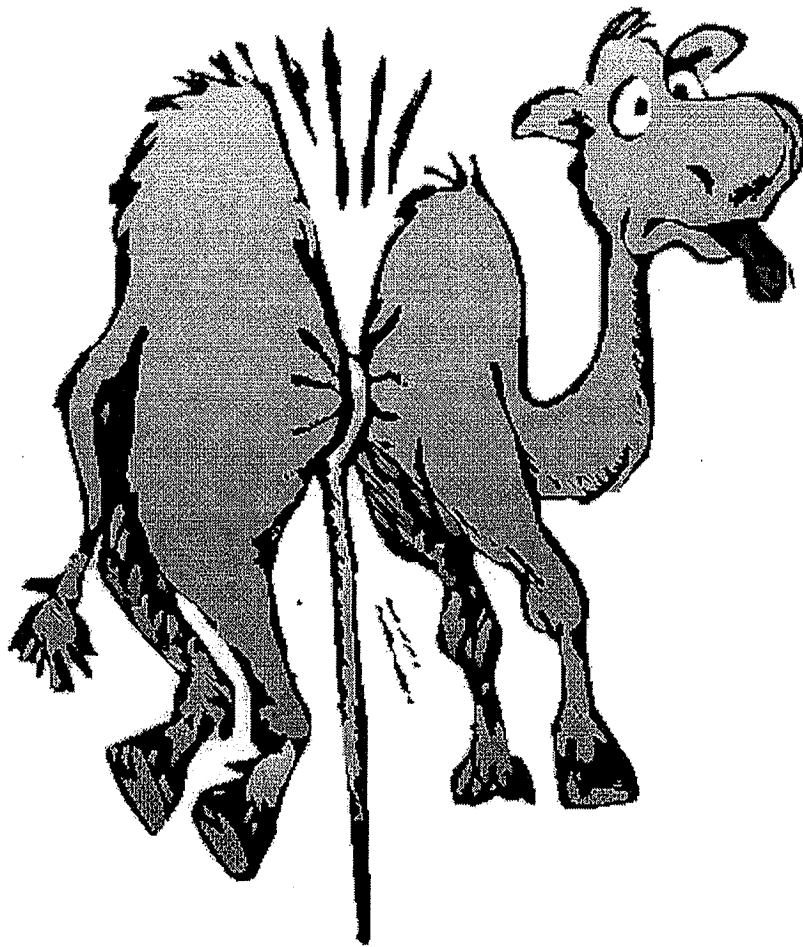
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3. Derive a relation between  $b$ ,  $\hat{b}$ , and the sample size  $n$ .

## **Bioimaging**

In the Bible (Matthew 19:24) it states "that it is easier for a camel to pass through the eye of a needle than for a rich man to go to heaven", while the Qur'an (Al-A'raf 7:40) says "those who deny and scorn God's message will not enter paradise until the camel goes through the eye of the needle". Recent advances in nanotechnology (funded by some very rich men); however, have resulted in the development of matter compression techniques that claim to be able to reduce a camel to a size that will allow it (the inventor's claim) to pass through the eye of a needle.

You, as a new hire, at ACME BioMeDimaging have been asked to design a biomedical imaging system to verify that a full grown camel (length 3 m, height at hump 2 m, width 1 m) can in fact pass through the eye of a typical sewing needle (length 3 mm, width 300 microns).



1. In order to impress your new boss you decide to demonstrate how all four of the principal forms of medical imaging (X-rays, ultrasound, nuclear medicine and MRI) can each be used to achieve your goal. Below please outline your approach and highlight the key tissue parameter needed for the success of your design.

A. X-ray/CT

B. Ultrasound

C. Nuclear Medicine

D. MRI

Name \_\_\_\_\_

2. For each system make an estimate of the sensitivity and imaging time.

A. X-ray/CT

B. Ultrasound

C. Nuclear Medicine

D. MRI

3. Which of your systems can distinguish the state of hydration of an adult camel (700 kg) using the fact that the hump of an adult camel contains approximately 35 kg of fat when the camel is fully hydrated.

A. X-ray/CT

B. Ultrasound

C. Nuclear Medicine

D. MRI

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