Quiz 2 – 2.75–2012, 1 November 2012 (Open Book)

Name: ____________________________________________________________

Please do your work in the exam book.

Problem 1 (60 Points):

Skin cancer is the most common cancer, with 2 million cases found annually in the US. Currently, it is “detected” by a doctor who feels the suspected lesion and surrounding skin. Cancerous lesions typically “feel harder” and it is by experience that the clinician decides when to biopsy.

We propose designing an instrument to enable a person, with many possible suspect lesions, to perform at-home checks and send data to their dermatologist, who will determine if tissue properties have changed enough to warrant an office visit. Many researchers are trying to develop this type of device and strategies vary from miniature MRIs to ultrasound elastography, but we think there is a simpler, cheaper way.

Our strategy is a vibrating stylus that, as it is moved across the skin, senses changes in tissue which correlate with the potential presence of a lesion. The current most critical module concept is a stylus attached to a bending beam, a vibrating actuator and a displacement sensor. The displacement sensor works by shining a laser diode onto the end of the bending beam and then measuring where the reflected beam is received on a linear diode array above the beam.

The vibrator (e.g. eccentric mass cell phone motor) delivers a sinusoidally varying vertical force to the beam at a regular frequency (well below any natural frequencies of system components). The device presses against the skin and is moved along the skin. As the stylus passes over the skin, its deflection changes in response to the stiffness and surface contours. Deflection is measured by the optical sensor described above.

Your task is to analyze the design and see if it is robust and doable.

   a. In your mind, move the system across the skin and describe what you think happens to the stylus… How does the system work and what are the uncertainties that it will have to robustly face? (10 points)

   b. Develop the analysis to characterize the quasi-static (ignore the vibrator for now) mechanical behavior of the device. (Use variables for system parameter, e.g., length, width, etc.) (20 points)

   c. Use the results of b) to evaluate the robustness of the system with respect to real physical issues that can occur with mechanical contact between the probe tip and the skin as it moves along: describe the risks and what countermeasures you would take to evolve the design to nullify the risks. (20 points)

   d. Given what you found above, sketch and comment on what the device should more realistically look like (other than the cartoon below). (10 points)
Problem 2 (40 Points):

Balistiocardigraphy measures the reaction force at the time the blood is released into the aorta. We use an accelerometer to measure the signal and convert acceleration to a voltage. The signal chain following the accelerometer has voltage gain and analog-to-digital conversion.

\[ \text{Accelerometer} \]
- Maximum signal \( 10mG \) P-P
- Signal bandwidth 9Hz
- Conversion gain \( 1V/G \)
- Noise spectral density \( 10^{-12} G^2/Hz \)

\[ \text{LNA} \]
- Gain = 100
- Bandwidth = 9Hz

a. Calculate the signal-to-noise ratio at the output of the accelerometer (input to LNA) when the maximum signal is applied. (Assume a noiseless LNA.) (5 points)

b. The LNA adds noise to the signal. The noise spectral density is \( 2 \times 10^{-8} V^2/Hz \) at the output of the LNA. Note that both the accelerometer and LNA contribute noise. Calculate the contribution to the noise spectral density of the LNA at its input. (10 points)

c. We want the peak signal at the input of the A/D converter to be \( 10V \) so we use its full dynamic range. (10 points)
   i. What is the voltage gain required for the amplifier after the LNA?
   ii. Design the gain stage using an OP AMP and \( 1k\Omega \) and \( 10k\Omega \) resistors.

d. The Anti Alias filter is a single pole RC filter with \( f_c = 10Hz \). Specify the minimum sampling frequency \( f_s \) to ensure that the noise spectral density aliased into the signal band is reduced by 100X. (10 points)

e. What is the minimum number of bits \( N \), for the ADC to accommodate the full dynamic range? (5 points)