Problem Set #2: Amplifiers and Comparators

DUE: Friday, 2013-01-31 at 5:00 PM in the grader box

1. **Instrumentation Amplifier** A graduate student at Duke is working on measuring axon action potentials that range in voltage from -100 mV to +50 mV. This student needs to amplify these signals before feeding them into additional signal processing equipment that will quantify the time constants associated with the axon firing. Design a three-op-amp differential amplifier (i.e., an instrumentation amplifier) that has a differential gain of 5 in the first (buffering) stage and a differential gain of 6 in the second (diff amp) stage. Clearly draw your circuit with all of the circuit elements and their values clearly labeled.

   Based on the specified range of the input signal, what are the minimum limits of the rail voltages of each op-amp to insure that the cumulative output of the amplifier remains in the linear range?

2. **Summing Amplifier** Ultrasound transducers are composed of many different piezoelectric elements, each of which is independently controlled electronically. In addition to using that electrical independence to focus the sound waves, it can also be used to control the amplitude of the sound wave sent and received from each element. Controlling these element amplitudes can be used to apodize the acoustic aperture to reduce side lobes of the focused sound wave, increasing the system's spatial resolution. This side lobe reduction is achieved by reducing the received voltage amplitudes of the elements on the ends of the aperture relative to the center elements before they are summed together. For a 5 element ultrasound transducer (E_{1-5}), design a summing amplifier so that two elements ($E_{2,4}$) adjacent to the center element (E_3) are 85% the center element's amplitude, and the outer elements ($E_{1,5}$) are 25% the center elements excitation voltage (i.e., $v_o = v_{E_3} + 0.85v_{E_2} + 0.85v_{E_4} + 0.25v_{E_1} + 0.25v_{E_5}$).

3. **Comparator** Design a comparator with a hysteresis range from 0 to +2 V. Make sure that you indicate the value of V_{ref}. Assume that the rail voltages of the op-amp are $\pm$ 13 V.

   Sketch the output of your comparator over three wavelengths of an input signal v_{in} = 4 $\sin(\omega t + \pi/4)$, for a frequency of 125.66 rad/s (20 Hz), starting at t = 0. (Sketch the output and input on the same set of axes.)

4. **Design: Pulmonary Hypertension Alarm** An anesthesia monitoring system is measuring the pressure output from a Swan-Ganz pulmonary artery catheter to evaluate pulmonary hypertension intraoperatively. Since the anesthesiologist is also monitoring several other physiologic systems concurrently (e.g., ECG, EEG, respiratory rate, blood pressure, etc.), the pressure monitor sounds an alarm when the pressure goes too high or too low. The pressure output of the catheter, ranging from 0 - 100 mm Hg, is linearly mapped to voltage through its transduction mechanism to be 0 - 10 V. Design a circuit using a comparator that will sound the alarm when the pressure rises above 25 mmHg. Assume that the pressure catheter signal has a noise component of $\pm$ 0.1 mmHg; your comparator should have a hysteresis range that is twice this noise limit. Let your input signal to the circuit from the pressure catheter be represented as v_{in}. Use DC power sources as needed in your circuit design, and specify the rail voltage(s) for the op-amp(s). The alarm can be considered a "black box" load that can be activated with a voltage greater than 5 V ($v_o > 5$ V).

5. **More Design: Low & High** Using a second comparator, modify your circuit in the previous problem so that the alarm will sound when the pressure rises about 25 mmHg or falls below 10 mmHg. You

want to use the same alarm for both conditions, so you will need to use another type of circuit component we discussed in class to combine the outputs of the two comparators to drive the alarm.

6. **Rechargeable, battery-powered devices** are becoming more ubiquitous in the medical setting. Compare/contrast these four types of rechargeable batteries in terms of energy density, output voltage, battery life, recharge time, and weight: (1) lead acid, (2) NiCad, (3) NIMH, and (4) Li-ion.

   Li-ion batteries have become very common in cell phones, digital cameras, laptop computers, and many other portable electronic devices. Unfortunately, there is also a non-negligible fire risk associated with these devices. What is responsible for this fire risk, and what safeguards do modern versions of these batteries utilize?