BENG 186B Principles of Bioinstrumentation

Week 1 Review

Exercises

Selections from:

2015 Homework 1
2015 Homework 2

BENG 186B Winter 2015 HW #1

Due *Thursday, January 15* at the beginning of class

1. You have three *analog to digital converters* (ADC) listed below. An ADC can measure a voltage to produce a binary value to be read by a computer. For each ADC, calculate the maximum number of distinct binary values it can produce, and the voltage step that the least significant bit (LSB) represents. Assume that the voltage range is 0 V to 5 V minus one LSB in all cases.

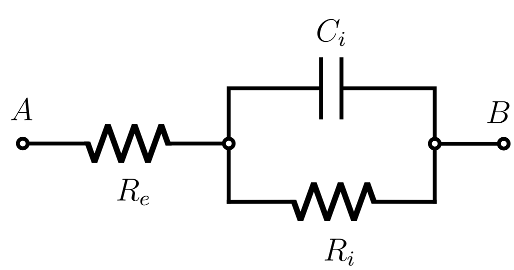
   (a) 8-bit ADC

   (b) 12-bit ADC

   (c) 16-bit ADC

2. *Bioelectrical impedance analysis* (BIA) can be used to estimate the percent level of fat in the human body. Although it is not the most accurate method, it does have the advantage of being very non–invasive and convenient. Higher–end digital body weight scales nowadays include BIA capabilities and are available in retail stores for consumer use.

   The impedance of the human body is roughly approximated as the following circuit, where R_e is the resistance of the extracellular fluid, R_i is the resistance of lipids (fat) separating extracellular and intracellular fluids and C_i is the corresponding capacitance, approximating the contribution by cell membranes.



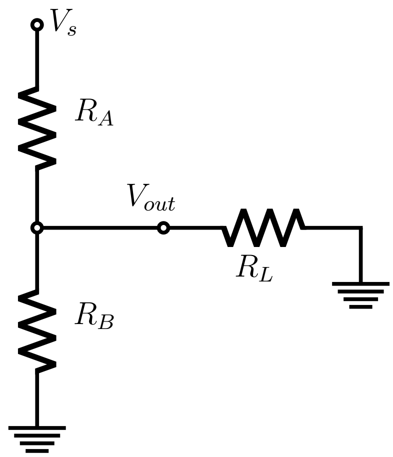
   (a) Write down an expression for the impedance between terminals A and B as a function of radial frequency ω.

   (b) What is the magnitude of the total impedance as a function of ω?

   (c) What is the phase of the total impedance as a function of ω?

   (d) ADCs measure only voltage and cannot measure impedance directly. Briefly describe one way to convert an impedance into a voltage.

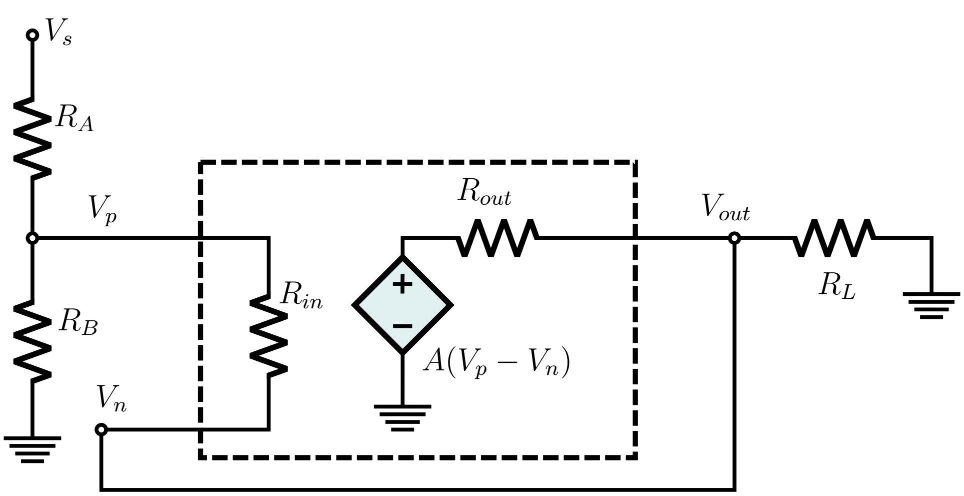
3. A group of scientists want to power a device using a battery to supply a constant voltage. The voltage of the battery V_s is too high for the device to operate, so they attempt to lower the supply voltage using a *voltage divider*. Shown below is their setup. The device is represented as a load resistance R_L and is connected to the voltage divider via V_{out}.



   (a) Develop an expression for V_{out} in terms of V_s and the resistances.

   (b) In general, R_L is not known in advance and it changes as the device operates. Given this fact, and the expression you derived in part (a), why won't the above circuit do the job?

   (c) You come in to save the day by adding an *amplifier* (shown below inside the dashed box), between the voltage divider and the device. In addition, you connect the amplifier's output V_{out} to V_n, so that $V_n = V_{out}$. The voltage–dependent voltage source is given as $A(V_p - V_n)$, where A is the amplifier gain.



   This time, develop an expression for V_{out} in terms of V_s, A, and the resistances. *Hint:* start by applying Kirchhoff's current law at the node labeled V_{out}. You may use conductances $G = 1/R$ instead of resistances to simplify the algebra.

(d) Take the limit of the V_{out} expression you obtained in part (c) as $A \to \infty$ and as $R_{in} \to \infty$. Does this new expression depend on R_L?

(e) Using the expression from part (d), what is the current flowing through R_{in}? Does this current depend on R_L?

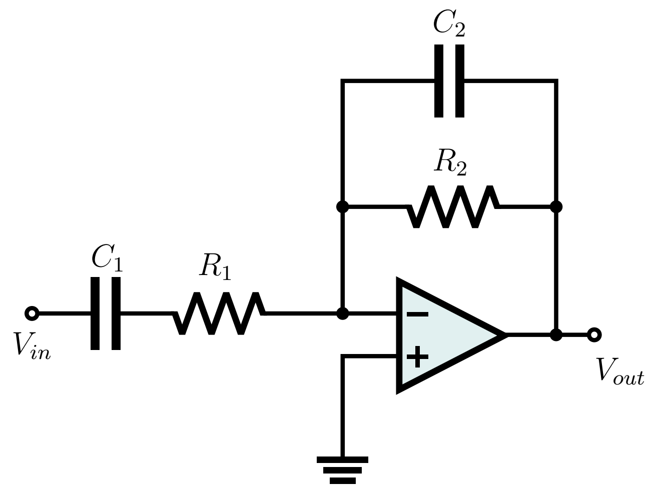
4. **Design Problem:** Consider an ADC that operates at a sampling rate of 100 kHz to digitize a voltage signal up to 1 V. Assume this ADC has infinite input impedance. Design a first–order filter, using only resistors and capacitors (with known component values) to reduce any aliasing effects. You may assume that any needed value for your resistors and capacitors is available at your disposal. Your circuit should not draw more than 10 µA of current from the input. Be sure to justify your choice of component values.

   General note for design problems: For this and all future design problems, make sure to sketch your design and outline the solution approach. Label all electronic parts with values, and label other components (*e.g.* label switches with the type of switch, a sensor with its type, and also their function). Show the equations you used to get the values or results. State your assumptions, if any. If a part or component value was arbitrarily chosen, indicate this in the solution. You will be graded not only on the final answer, but also the design approach and presentation of the problem and its solution. Neatness counts!

BENG 186B Winter 2015 HW #2

Due *Thursday, January 29* at the beginning of class

1. Consider the following band–pass filter:

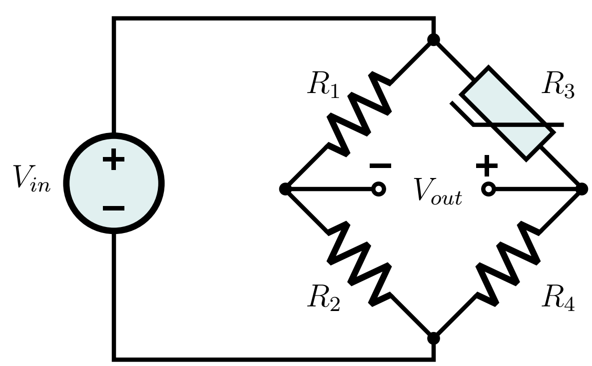


   (a) Find the transfer function $H(j\omega) = V_{out}/V_{in}$. Assume the op–amp is ideal.

   (b) Propose values for the circuit components such that the filter has a gain of 30 dB and a pass-band of 20 Hz to 20 kHz.

   (c) Draw a Bode plot of the filter response.

2. Consider the following circuit for a thermometer:



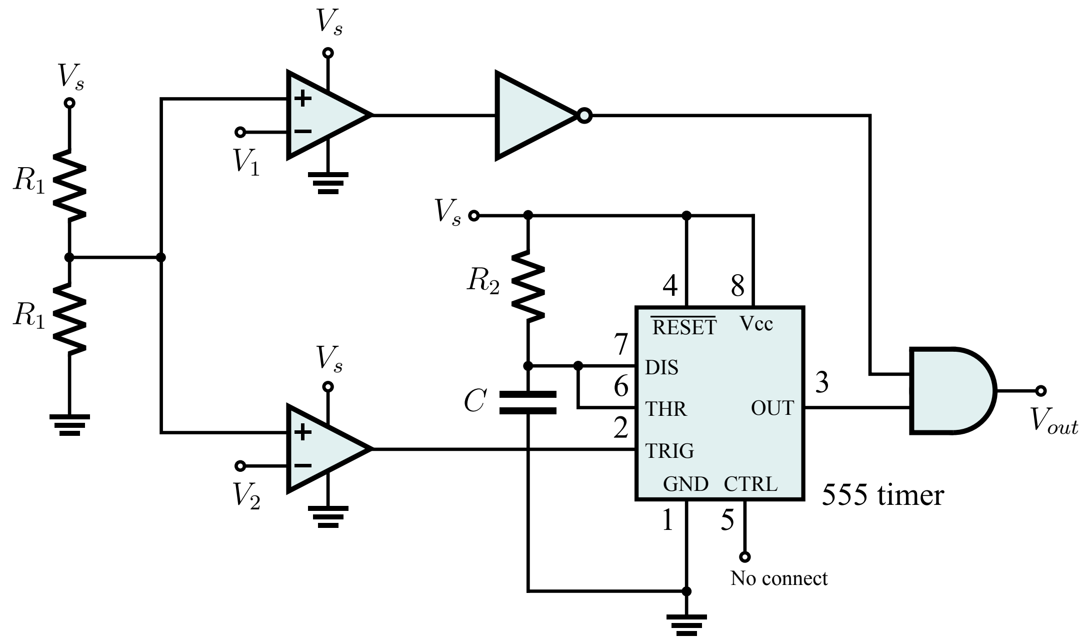
   R_3 represents a thermistor with a transfer function $R_3(T) = r_\infty e^{\beta T}$, where β and r_∞ are constants, and T is temperature.

   (a) Write the voltage output V_{out} of the system as a function of temperature T. Pay attention to the polarity of V_{out}.

   (b) What is the sensitivity of the thermistor's resistance with respect to temperature? In other words, calculate dR_3/dT.

   (c) What is the sensitivity of the voltage output V_{out} with respect to T?

3. Consider the following circuit with $V_s = 5\,\text{V}$, $R_1 = 1\,\text{k}\Omega$, $R_2 = 25\,\text{k}\Omega$, and $C = 9.1\,\mu\text{F}$:



Two biosensors being worn by a patient output voltage signals V_1 and V_2. V_1 is 0 V for $t \leq 0$ s, then ramps linearly from 0 V to 5 V over the interval $0\,\text{s} \leq t \leq 2\,\text{s}$, and finally remains at 5 V for $t \geq 2$ s. V_2 is a square wave with an amplitude of 2.6 V (*i.e.*, pulsing from 0 V to 2.6 V), a period of 500 ms, and a duty cycle of 30 %. V_2 starts pulsing at $t = 0$ s.

(a) Sketch V_1, V_2 and V_{out} from $t = 0$ s to $t = 2$ s.

(b) What tolerance is required of the resistance value R_1 in order for this circuit to operate correctly for the given input signals. Explain.

4. **Design Problem: Portable Cytotoxicity Measurement Device**

Cytotoxic assays offer an effective means to measure the toxicity of a variety of compounds. These assays are performed by growing cells on a substrate, then exposing them to the compound. If the compound is toxic, the cells will begin to die and undergo lysis. Cell death is usually measured by chemically labeling the cell with fluorescent agents. As cells begin to die, the fluorescent signal will change. Therefore, cell death is directly correlated with fluorescence intensity. However, this method is cumbersome and expensive, requiring means to attach fluorescent markers to the target cells, and wavelength selective light sources and detectors.

An anti–bioterrorism agency tasked you with designing a label–free electronic method of testing the cytotoxicity of unknown compounds, anywhere in the field. For this purpose you make use of two samples of cells grown on two electrically conducting substrates in a Petri dish: a test sample to be exposed to the unknown compounds, and a control sample shielded from any compounds. You have to design two identical sensors, one for each sample, that couple electrically to the substrate in order to record impedance through the layer of cells.

You also need to design a decision circuit that will detect, based on relative impedance, if the cells in the test group exposed to the compound are dying compared to the control group.

This label-free electrical method is known as electric cell-substrate impedance sensing (ECIS). *Principle:* Healthy cell membranes are essentially non-conductive, with impedance limited by capacitance. When cells die, their membranes degrade, causing them to leak current and leading to a decrease in impedance, mostly a decrease in resistance.

Your design must meet these specifications:

- For each sensor, inject a current signal to probe the impedance by measuring voltage. Do this separately for the control group of cells, and the test group of cells.
- Don't expose cells to more than 10 μA of current for more than 10 μs at a time, otherwise you will kill them.
- This device needs to be portable (powered by batteries), as it will be used in remote locations.
- To save power, the device should only probe/sense cells once every 100 ms.
- The sensor output must be indicated by two LEDS (green and red). As long as the resistance of the test group is greater than one half the resistance of the control group, the green LED should remain lit. Otherwise, the red LED should be lit.

(a) Illustrate the design and briefly (no more than 3 to 4 sentences) describe the principles of operation of your system. Draw a conceptual system-level diagram outlining the major building blocks of the system, including sensors, decision circuit, and output display.

(b) Show a full circuit schematic for your instrument along with equations calculating the values of all resistors, capacitor and other circuit parts. Indicate part numbers for op-amps, timers and other active elements. Indicate the gain or sensitivity of each transducer part of the circuit.

(c) Sketch waveforms for the behavior of the measured quantities and corresponding voltages at different stages in the circuit to clarify the operation. Remember to label all axes and explain what your calculations are showing.

(d) **Bonus:** List some possible problems with your design/idea. How would you solve these problems?