BENG 186B Winter 2015

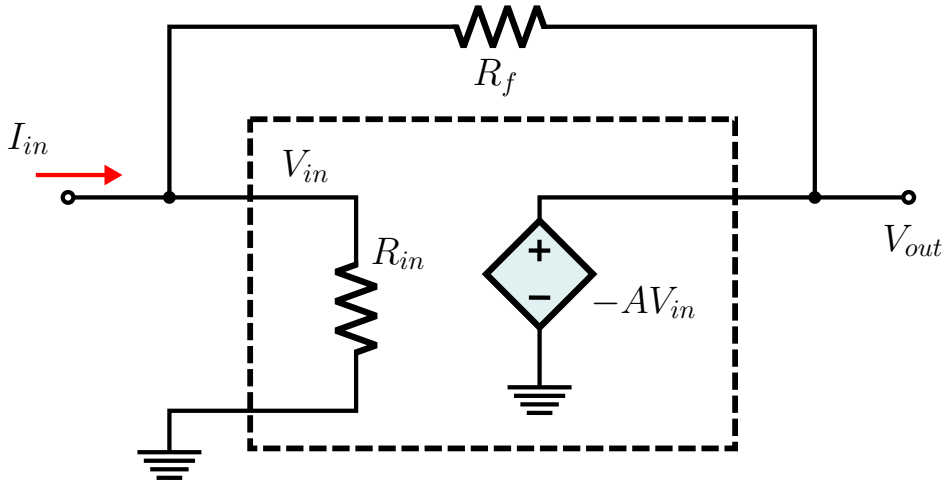
Quiz 1

Wednesday, January 21, 2015

Last Name, First Name: _____

- This quiz is closed book and closed notes. You may use a calculator for algebra and arithmetic.
- This quiz has 10 pages, including this cover sheet. Do not attach separate sheets. If you need more space, use the back of the pages.
- Circle or box your final answers and show your work on the pages provided.
- There are 4 problems. Points for each problem are given in **[brackets]**. There are 100 points total.
- You have 50 minutes to complete this quiz.

1. **[30 pts]** You have an optical sensor that produces a current I_{in} in response to light intensity. You connect this sensor to a current-input, voltage-output device shown below. The dashed inset shows the Thévenin equivalent linear circuit of a voltage amplifier internal to the device.



(a) Derive, **from first principles**, the expression for output voltage V_{out} in terms of input current I_{in}.

(b) Now consider that the internal voltage amplifier is ideal, with infinite voltage gain $A \to \infty$, and infinite input impedance $R_{in} \to \infty$. Find the resulting expression for the output voltage V_{out}. In other words, evaluate:

$$\lim_{A \to \infty} \lim_{R_{in} \to \infty} V_{out} = \ ?$$

(c) According to the V_{out} expression from part (b), what is the gain of the device? What unit is this gain expressed as?

(d) Suppose you need this device to convert an input current signal of 10 μA amplitude to an output voltage signal of 1 V amplitude. According to the V_{out} expression from part (b), what numerical value should R_f be set to?

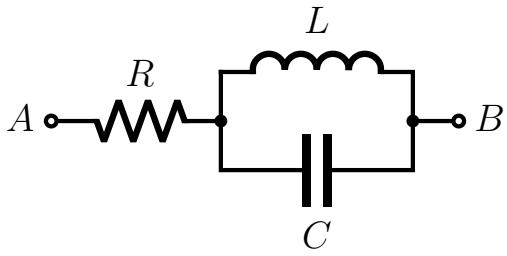
2. **[30 pts]** A photoplethysmograph device can be used to determine heart rate. However, it produces voltage signals that are superimposed on top of a large DC component. You need to design a filter to remove the DC component from the voltage signal.

   (a) Draw a generic first–order filter circuit suitable for this purpose. Use variables to represent the component values. **Label the voltage input and voltage output nodes clearly.** What kind of filter is this? (low–pass, band–pass, *etc*.)

   (b) The heart rate of athletes can be as low as 40 beats per minute. Given this information, propose a set of numerical component values that are appropriate for this filter.

(c) Draw Bode (magnitude and phase) plots of this filter. **Be sure to label the plots, including any significant features and all axes.**

3. **[25 pts]** MRI machines contain RF transceivers that need to be tuned to certain frequencies. One way to do this is to use a *tank circuit*:



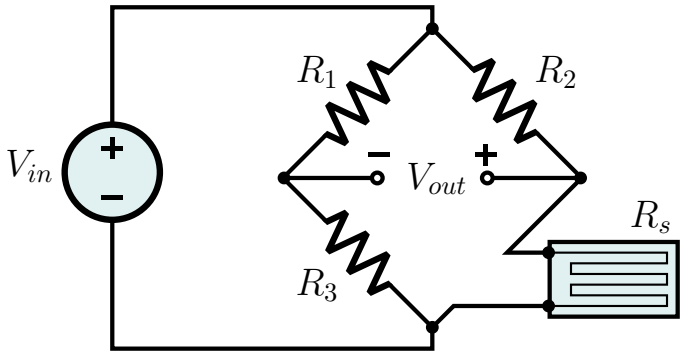
(a) What is the total impedance between terminals A and B in terms of ω? **Write your answer in standard form ($a + jb$).**

(b) What is the magnitude of the total impedance in terms of ω?

(c) What is the phase of the total impedance in terms of ω?

(d) This particular circuit is said to be *resonant* when it exhibits infinite impedance. At what ω will this happen?

4. **[15 pts]** You are tasked with testing the mechanical properties of a new material that will be used for a prosthetic leg. You first try constructing the circuit below for this purpose:



Here, the strain gauge has a resistance $R_s = R_G(1 + G\varepsilon)$, where R_G is the nominal resistance, G is the gauge factor, and ε is the strain.

(a) Find the output voltage V_{out} as a function of the strain ε. You may assume that no current flows between the V_{out} terminals.

(b) For a given gauge factor G and nominal resistance R_G, find values for the resistances R_1, R_2 and R_3 that zero the voltage offset and maximize the sensitivity of the strain sensor.

(c) After gathering some data, you notice some inconsistencies between runs. A colleague suggests to you that it might be due to temperature fluctuations in the room. Describe one way you can modify the above circuit to compensate for this.