**BENG 186B Winter 2025 HW #1**

Due by *Friday, January 17* at 11:59pm on Canvas (Gradescope)

Parts of the homework done collectively in-class (Friday, January 10) are indicated below with **[IC]**.

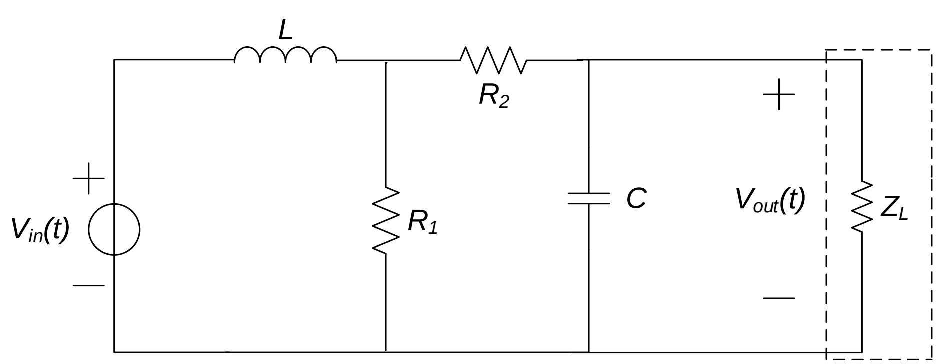
1. [**20 pts**] Consider a bioinstrumentation amplifier interfacing with electrodes to measure a biopotential signal originating from the body. The voltage signal picked up by the electrodes, placed in direct contact with the skin, is subject to $10\,\mu\text{V}$ root-mean-square amplitude of additive noise due to the electrode-skin interface. The amplifier has a sensitivity of 1,000 over its linear range, with output ranging from -0.5V to +0.5V, and saturates with zero sensitivity outside of this range. The amplifier has an input-referred offset of $-100\,\mu\text{V}$. The amplifier output is converted to digital samples, at 10 kHz sampling rate, by an analog-to-digital converter (ADC) with 12-bit resolution covering the entire -0.5V to +0.5V output range of the amplifier.

   (a) **[IC]** [5 pts] Find the accuracy, precision, and resolution of the biopotential signals measured by the instrument. Compare the three, and explain the differences.

   (b) [5 pts] Find the range of biopotentials over which the instrument produces a valid measurement. How can you detect whether the biopotential signal is outside of this range?

   (c) [10 pts] What is the maximum frequency of biopotential signals that can be reconstructed from its samples produced by the ADC, and what happens to a signal above that frequency? Illustrate what you would observe at the digital output when you present the amplifier input with a $200\,\mu\text{V}$ peak-to-peak sine wave signal of frequency 9.9 kHz.

2. [**40 pts**] Consider the following filter circuit with voltage input $V_{in}$ and voltage output $V_{out}$, driving an output load $Z_L$. The values for the internal components are $R_1 = 10\,\text{k}\Omega$, $R_2 = 1\,\text{k}\Omega$, $C = 1\,\text{nF}$, and $L = 1\,\mu\text{H}$.




   (a) **[IC]** [10 pts] Find the input impedance, and output impedance. *Hint*: assume an ideal load $Z_L$ as usual.

   (b) [5 pts] Derive the Thévenin equivalent of the circuit at the input, and at the output.

   (c) [10 pts] Write the transfer function $V_{out}(j\omega)/V_{in}(j\omega)$, and graph your result as a Bode plot (log amplitude and phase vs log frequency).

   (d) [5 pts] At steady state for $V_{in} = 1\text{V}$, find the power dissipated by the circuit. Assume there is no output load ($Z_L = \infty$).

(e) [10 pts] Now find the power transfer efficiency (ratio of power delivered to the load, over power delivered by the source) at steady state as a function of the load $Z_L$ added to the output. What value of $Z_L$ gives maximum efficiency?

3. **Design Problem [40 pts]:** Action potentials, or "spikes", are fast pulsing voltage events generated by electrically active cells such as neurons in the brain. They can be recorded from multiple neurons simultaneously using a microelectrode array (MEA) inserted in neural tissue; however, reliable measurement of spikes requires proper filtering of the electrode signals to eliminate signal interference and noise. In this problem we will design a bandpass filter for spike recording from a MEA that eliminates both low-frequency contaminating signals such as slow local field potentials, and high-frequency noise in the electrode and measurement circuits.

   Design a voltage-in, voltage-out continuous-time analog bandpass filter with unity gain in the midband, 10 Hz and 10 kHz -3dB corner frequencies, and 20dB/decade roll-off outside the midband (*i.e.* $+20$dB/decade below the 10 Hz frequency corner, and $-20$dB/decade above the 10 kHz frequency corner). You may use any combination of resistors, capacitors, and inductors. Your circuit should not draw more than $1\,\mu$W of power from the input ranging $-100\,\text{mV}$ to $+100\,\text{mV}$. Be sure to justify your choice of component values, and give consideration for their practical realization.

   **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!