12-778 Fall 2022: Assignment #2

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Instructions

When answering the following questions, please provide all of your calculations to arrive at the answer (in addition to the answer itself). Your calculations should be very clear and easy to understand. They should include your assumptions, and a step-by-step explanation of how you arrived at the solution. Also, make sure you type your name and AndrewID somewhere on the first page, and that you clarify who you worked with in developing the intuitions behind your answer.

Some other recommendations:

- Before finding the answer to each question or looking at the next step in the solution, take some time to think about how you can come up with this on your own.
- Again, make sure you document everything you do, and not just write down the answer to the question. This will both help during grading as well as improving your learning process.
- Do not write down any solution or process that you do not understand. If you feel that you do not understand how to do something, seek some help. The preferred method for this is to post your questions on the discussion board for the course (i.e., Piazza).

Electrical Circuit Theory (15%)

Capacitance (7.5%):

For a capacitor with capacitance C and voltage V, why is the following equation true?

$$w = C \int_0^V v dv = \frac{1}{2} C V^2$$

Impedances (7.5%):

Is the resistor the only elementary circuit element that produces a voltage drop in a dc circuit? Why or why not?

Signal Conditioning (30%)

Input signal range (10%)

Sometimes (e.g., when a signal has negative values but our analog to digital converter has an input range that only considers positive signals), a a signal conditioning circuit that biases the signal to be entirely positive becomes useful. A relatively simple circuit that can be used for this purpose would be a voltage divider. Let's assume thay you are sampling a signal that is in the range -3V to 3V with the ADC in your Raspberry Pi Pico. Please provide a design for such a circuit including the values of the impedances (resistors in this case), an expression for the the source and output voltages, and proof that the signal would fall within the input range for the ADC in the Pico.

Interstage loading errors (10%)

When conneting different stages of our instrument (e.g., an analog device to an A/D converter), why is it that for current source inputs, we want to have Z_2 (the impedance of the next stage) be smaller than that of the source? Can you derive the expression for the loading error in this case (i.e., $e_I = I_2 - I_1$ where I_1 is the current that would circulate if we short-circuit the terminals of our first device – the source – and I_2 is the current that is pushed through the second device when connected)? Why is it $e_I = V_1 \frac{-Z_2}{Z_1^2 + Z_1 Z_2}$?

Wheatstone Bridges (10%)

In class, we saw the derivation of the Wheatstone bridge and showed why the full-bridge had better properties for strain measurements than other configurations. We also said (but did not prove) that the half-bridge configuration was *better* than a voltage divider or the single/quarter bridge configuration. Here, I'm asking you to prove that. Signal Characteristics (45%)

Solve problem 2.4 from Chapter 2 of Figliola (5%)

Solve problem 2.7 from Chapter 2 of Figliola (5%)

Solve problem 2.11 from Chapter 2 of Figliola (10%)

Solve problem 2.15 from Chapter 2 of Figliola (15%)

Solve problem 2.24 from Chapter 2 of Figliola (10%)

High-speed sampling (10%)

Find an analog sensor that can be used to measure a physical phenomenon with interesting dynamic properties (e.g., accelerometer, microphone, etc.) and, using proper signal conditioning and sampling strategies, obtain measurements of this phenomenon using the sensor and your Raspberry Pi Pico at a sampling rate of at least 1000Hz. Compare the results of the sampling calling the ADC using machine.ADC.read_u16() and using the DMA trick we showed in class. Submit a sketch of the signal conditioning circuit, the Python code that needs to run on the Pico, two CSV files showing your sampled signals, and a written explanation of what you found during the process.