• This quiz is on-line, open-book, and open-notes, but web search is prohibited. You may follow electronic links from Canvas or the class web pages, but not any further. **No collaboration or communication in any form is allowed**, except for questions to the instructor and TAs.

• The quiz is due January 27, 2023 at 11:59pm, over Canvas (Gradescope). It should approximately take 2 hours to complete, but there is no time limit other than the submission deadline. Do not discuss any class-related topics among yourselves before or after you have completed your quiz, and until the submission deadline has passed.

• There are 3 problems. Points for each problem are given in **[brackets]**. There are 100 points total.
1. [20 pts] Circle the best answer (only one answer per question):

(a) [4 pts] The precision of a bioinstrument is affected by:
   i. systematic offset.
   ii. measurement noise.
   iii. saturation.
   iv. all of the above.

(b) [4 pts] An inductor-capacitor undamped second-order system:
   i. oscillates at its natural frequency.
   ii. produces unbounded output when driven with an input at the natural frequency.
   iii. conserves energy.
   iv. all of the above.

(c) [4 pts] The Norton equivalent of a linear circuit is:
   i. an ideal voltage source in parallel with an impedance.
   ii. an ideal voltage source in series with an impedance.
   iii. an ideal current source in series with an impedance.
   iv. an ideal current source in parallel with an impedance.

(d) [4 pts] The gauge factor of a strain gauge depends on:
   i. resistance.
   ii. Young’s modulus.
   iii. Poisson ratio.
   iv. all of the above.

(e) [4 pts] The sensitivity of an inductive displacement sensor depends on:
   i. the number of windings of the inductive coil.
   ii. the magnetic susceptibility of the magnetic core.
   iii. its geometry.
   iv. all of the above.
2. [40 pts] Consider the current-input, voltage-output filter circuit below.

(a) [10 pts] Find the input impedance $Z_{in}(j\omega)$. 
(b) [10 pts] Find the output impedance $Z_{out}(j\omega)$. 
(c) [10 pts] Find the transfer function \( H(j\omega) = \frac{V_{\text{out}}(j\omega)}{I_{\text{in}}(j\omega)} \). What are the units?
(d) [10 pts] Sketch the Bode plot of the transfer function $H(j\omega)$ for $C = 1 \text{ nF}$, and $R_1 = R_2 = 1 \text{ k}\Omega$. Be sure to label the axes and indicate the units.
3. **[40 pts]** Consider the strain transducer below, with constant supply voltage $V_s = 1 \text{ V}$, and four strain gauges $R_1$, $R_2$, $R_3$ and $R_4$ all with identical nominal resistance $R_{\text{nom}} = 100 \text{ k}\Omega$, and gauge factor $G = 100$. The transducer produces a differential output voltage $V_o$ in response to positive strain $\epsilon$ applied to two of the strain gauges $R_1$ and $R_4$, and exact opposite negative strain $-\epsilon$ applied to the other two strain gauges $R_2$ and $R_3$.

\[ R_1 = R_4 = R_{\text{nom}} (1 + G \epsilon) \]
\[ R_2 = R_3 = R_{\text{nom}} (1 - G \epsilon) \]

(a) **[5 pts]** Find the output voltage $V_o$ as a function of strain $\epsilon$. Is the response linear, and why?
(b) [5 pts] Find the sensitivity and offset of the strain transducer.
(c) [10 pts] Now consider that the gauge factors of both $R_1$ and $R_2$ are 10% smaller than expected, whereas the gauge factors of both $R_3$ and $R_4$ are 10% larger than expected. Find the sensitivity and offset of the strain transducer, and compare with (b). Explain what you observe.
(d) [10 pts] Now consider that the strain gauges $R_1$ and $R_3$ have identical temperature coefficients $\alpha = 0.01 \, \text{C}^{-1}$, whereas the strain gauges $R_2$ and $R_4$ are temperature independent. Find the sensitivity of the transducer output voltage $V_o$ to temperature $T$, at zero strain $\epsilon = 0$. Explain what you observe.
(e) [10 pts] Find the worst-case absolute accuracy of digital reading of the strain using a 12-bit analog-to-digital converter that spans a 100 mV range at the output of the strain transducer.