General Instructions

- This exam consists of three questions on analog electronics, each with equal weight (25 points). Each question has subquestions, with point weights as indicated in the text of the exam.

- Write all answers on the exam paper. Please box your answers.

- It is recommended that you show work for your results – it is difficult for the grader to give partial credit on problems with no work shown.

- You may use a calculator (standard arithmetic functions only), but no notes or text.

- The duration of the exam is 50 minutes.
Question 1: Consider the filter below with component values as listed.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{filter_diagram.png}
\caption{Filter Circuit Diagram}
\end{figure}

\begin{itemize}
    \item[a)] Characterize this filter as a low-pass or high-pass filter and determine the characteristic frequency $\omega_0$ (in radians/sec). (5 points)

    \item[b)] Design an equivalent filter circuit using a capacitor instead of an inductor. Draw the schematic for the filter and determine the necessary capacitor value to have the same $\omega_0$ when reusing the same resistor. (10 points)
\end{itemize}
c) Determine the output amplitude for an input signal with $f = 40\, \text{Hz}$ and input amplitude $V_{in} = 5\, V_{\text{peak-peak}}$, assuming an ideal inductor. (5 points)

d) A real inductor will have an internal resistance as well as an inductance. If we can model the real inductor in use as an ideal inductor in series with a 10 $\Omega$ resistor, what will be the attenuation of the circuit at very low frequency? (5 points)
Question 2: You are called in by a colleague to help improve the performance of a measurement – the original measurement apparatus was designed by a student who has long-since graduated and departed for new challenges. The measurement depends on a custom-built flow meter which converts fluid flow (in nanoliters/minute) into a voltage signal. His measurements just don’t seem to be consistent with his calibration.

You take the sensor to your lab and determine that it produces a voltage output proportional to the flow rate \( f \)

\[ V_s = \alpha f \]

with a proportionality constant \( \alpha = 0.45 \text{ mV}/(\text{nL/s}) \). You also determine that the flow sensor has an output impedance of 20 k\( \Omega \).

Your colleague shows you the circuit he designed to amplify the output. You may assume ideal op-amp behavior throughout the analysis.

![Circuit Diagram]

a) Find the design gain of the amplifier, assuming a voltage input with zero output impedance (an ideal sensor). (5 points)

b) If the flow meter were an ideal sensor, what would be the output of the amplifier for a flow rate of 40 nL/s? (5 points)
However, the flow meter does have non-zero output impedance, which will change this behavior.

c) Given the actual output impedance of the flow meter, what will be the voltage $V_{in}$ (on input of the amplifier) when the flow rate is 40 nL/s? (5 points)

d) Find the output voltage of the amplifier when the flow rate is 40 nL/s, using the realistic sensor characteristics. (5 points)

e) If your colleague was using the ideal sensor assumption, what would he think the flow rate would be (when it was actually 40 nL/s)? (5 points)
Question 3: For this problem, you will consider the three similar circuits shown above. You may assume the forward diode drop is 0.6 V and that the reverse breakdown voltage is very large.

a) Determine the output voltage relative to ground and the output impedance for Figure a. (11 points)
b) Determine the output voltage relative to ground for Figure b. (7 points)

c) Determine the output voltage relative to ground for Figure c. (7 points)