BEGN 186B Winter 2025

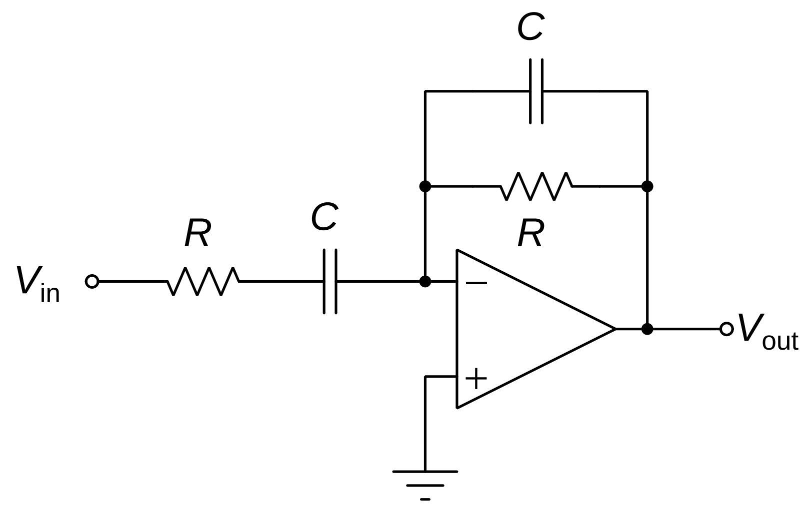
Quiz 2

Friday, February 14, 2025

Last Name, First Name: ______________________________

- This quiz is on-line, open-book, and open-notes. You may use a calculator or an equivalent program, 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 February 14, 2025 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 4 problems. Points for each problem are given in **[brackets]**. There are 100 points total.

1. **[30 pts]** Consider the voltage-in, voltage-out active filter circuit below:



(a) [15 pts] Assume the operational amplifier is ideal and unsaturated. Derive the transfer function $H(j\omega) = V_{out}(j\omega)\,/\,V_{in}(j\omega)$. What type of filter is this? Identify the poles and zeros, and the frequency at which the transfer function $H(j\omega)$ reaches its peak magnitude.

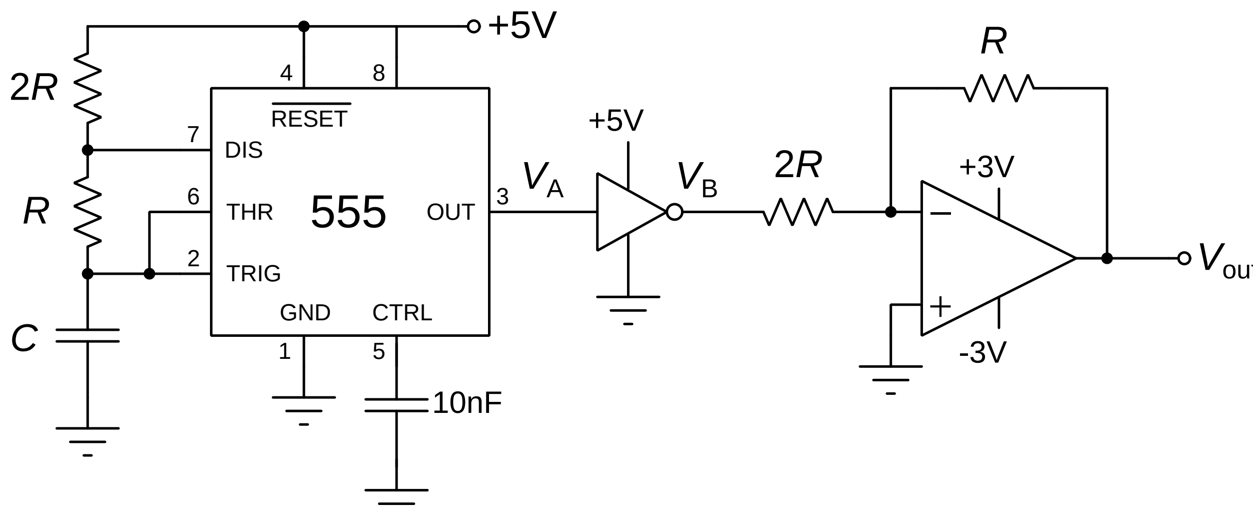
(b) [5 pts] What is the input impedance at the V_{in} node?

(c) [5 pts] What is the output impedance at the V_{out} node?

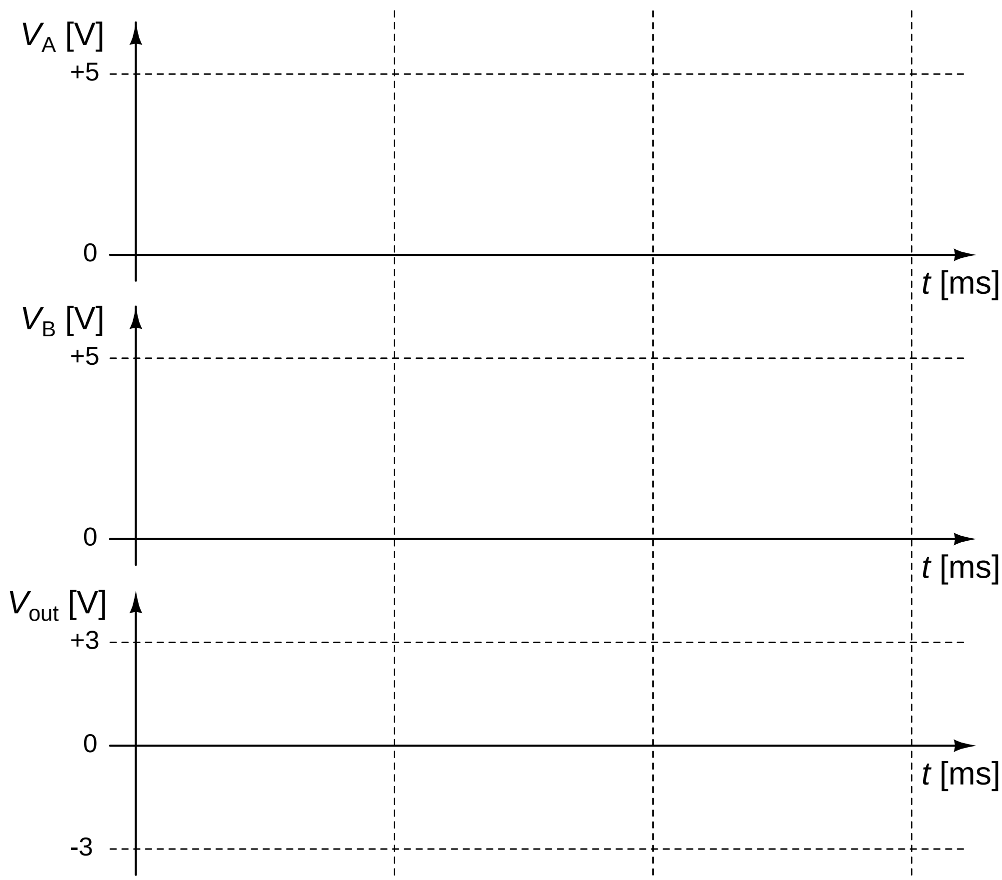
(d) [5 pts] Find the current supplied by the operational amplifier when the output node V_{out} is loaded by a resistance R_{load} to ground, and the input V_{in} is grounded.

2. **[35 pts]** Consider the signal generator circuit shown below. All active components are ideal. The 555 timer IC and the logic inverter operate from a +5V single supply, while the opamp operates from a dual +3V and -3V supply. The values for the passive components are $R = 360\,\text{k}\Omega$, and $C = 1\,\text{nF}$. You may also find the following equations useful for the 555 timer ($\ln(3) \approx 1.1$ and $\ln(2) \approx 0.7$):

$$T = \ln(3) \times RC \qquad T_{lo} = \ln(2) \times R_2 C \qquad T_{hi} = \ln(2) \times (R_1 + R_2)C$$



(a) [15 pts] Sketch the waveforms for the voltages V_A, V_B and V_{out} on the diagrams on the next page. Show your work below.

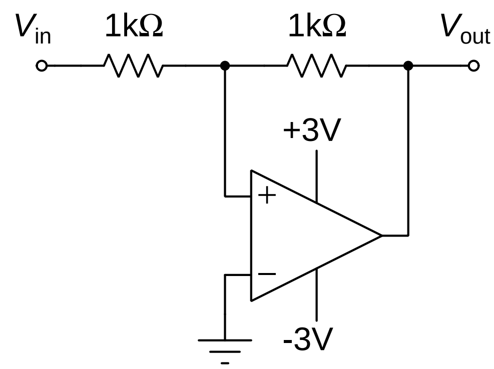

V_A [V]
+5
0
t [ms]
V_B [V]
+5
0
t [ms]
V_{out} [V]
+3
0
t [ms]
-3

(b) [5 pts] Does the output voltage V_{out} change if the ± 3V dual supplies of the opamp are replaced with ± 2.5V? Explain.

(c) [15 pts] Show how to change the circuit to output the same V_{out} waveform but without using any logic circuits. Can you do it without using any amplifier circuit? Explain.

3. **[20 pts]** Circle the **best answer (only one answer per question)**:

(a) [4 pts] The output V_{out} of the circuit shown at right (with an ideal opamp) goes high when the input V_{in} goes:



i. below 0

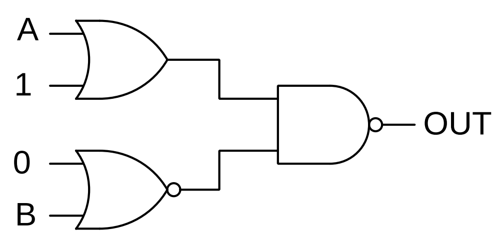
ii. above 0

iii. above +1.5V

iv. above +3V

v. below -3V

(b) [4 pts] Find the simplest logic expression for the output shown at right:



i. 0

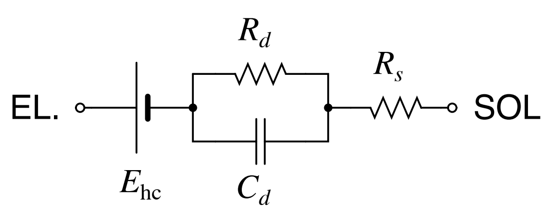
ii. A

iii. $\overline{\text{A}}$

iv. $\overline{\text{B}}$

v. B

(c) [4 pts] The electrode circuit model on the right for a polarizable electrode has:



i. low series resistance R_s

ii. low double-layer resistance R_d

iii. high double-layer resistance R_d

iv. large half-cell potential E_{hc}

v. none of the above

(d) [8 pts] Indicate for each statement below whether it is true or false:

i. **TRUE / FALSE**: A cell membrane without any permeable ion channels has infinite reversal potential.

ii. **TRUE / FALSE**: Local field potentials propagate through volume conduction in extracellular space.

iii. **TRUE / FALSE**: Ion pumps maintain concentration gradients across the cell to regulate constant reversal potentials.

iv. **TRUE / FALSE**: EOG can be clinically used to diagnose rapid eye movement (REM) sleep disorders.

v. **TRUE / FALSE**: EEG offers a finer spatial and temporal resolution than ECoG.

vi. **TRUE / FALSE**: The P wave of the ECG indicates ventrical repolarization.

vii. **TRUE / FALSE**: The Ag/AgCl electrode is consumed as a DC current passes through it.

viii. **TRUE / FALSE**: The electrode-skin contact impedance increases when sweat is present at the interface.

4. **[15 pts]** A signal electrode is inserted into the cell body of a neuron, and a second identical reference electrode is inserted into extracellular tissue far away from the cell. The ion concentrations inside and outside the cell are given in the table below. At rest (equilibrium), the cell membrane is equally permeable to Na^+ and K^+. The GHK equation at room temperature is:

$$V_m = 60\,\text{mV}\ \log_{10}\left(\frac{P_{\text{Na}}[\text{Na}^+]_o + P_{\text{K}}[\text{K}^+]_o + P_{\text{Cl}}[\text{Cl}^-]_i}{P_{\text{Na}}[\text{Na}^+]_i + P_{\text{K}}[\text{K}^+]_i + P_{\text{Cl}}[\text{Cl}^-]_o}\right).$$

	Inside	Outside
Na^+	5nM	50nM
K^+	50nM	5nM
Cl^-	55nM	55nM

(a) [5 pts] Find the voltage measured by the signal electrode relative to the reference electrode when the cell is at rest. Does it matter what the permeability to Cl^- is?

(b) [5 pts] The voltage measured by the signal electrode relative to the reference electrode is 60 mV when the cell is at the peak of its action potential. What does that imply in terms of the relative permeabilities of the cell to the three ion types?

(c) [5 pts] Why is it important that the two electrodes are of identical metal type? How would the voltages measured in (a) and (b) change when the two electrodes are of different metal types?