BEGN 186B Winter 2019

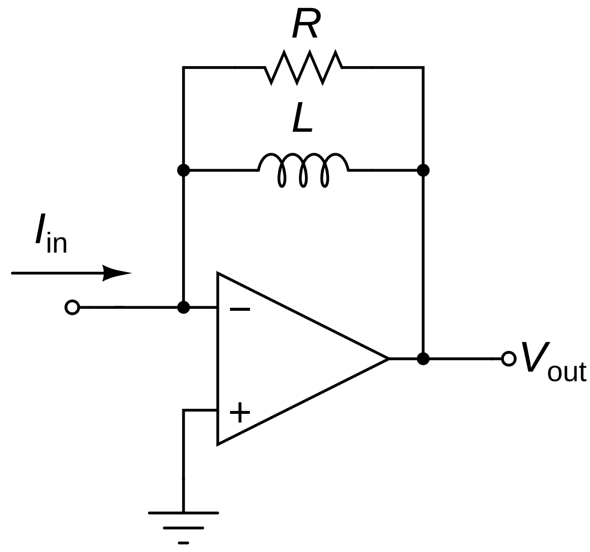
Quiz 2

Friday, February 15, 2019

Last Name, First Name: ____________________________________

- This quiz is closed book and closed notes. You may use a calculator for algebra and arithmetic.
- This quiz has 9 pages, including this cover sheet. Do not attach separate sheets. If you need more space, use the back of the pages.
- Circle or box your final answers and show your work on the pages provided.
- There are 4 problems. Points for each problem are given in **[brackets]**. There are 100 points total.
- You have 50 minutes to complete this quiz.

1. **[25 pts]** Consider the current-in, voltage-out active filter circuit below:



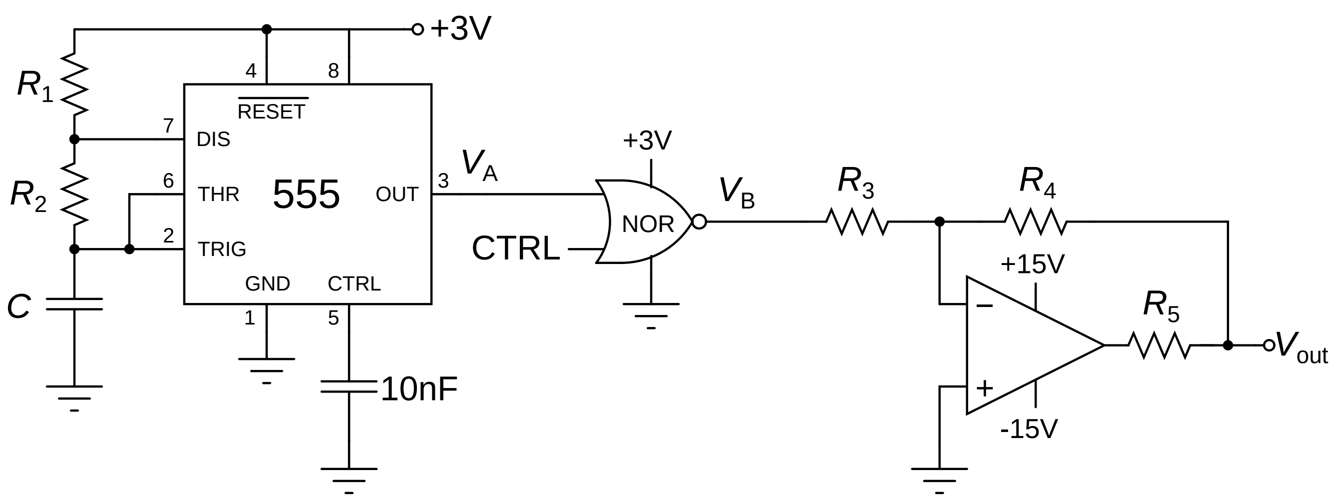
(a) [15 pts] Assume the operational amplifier is ideal and unsaturated. Derive the transfer function $H(j\omega) = V_{out}(j\omega) \,/\, I_{in}(j\omega)$. What type of filter characteristic is this? What is the cutoff frequency?

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

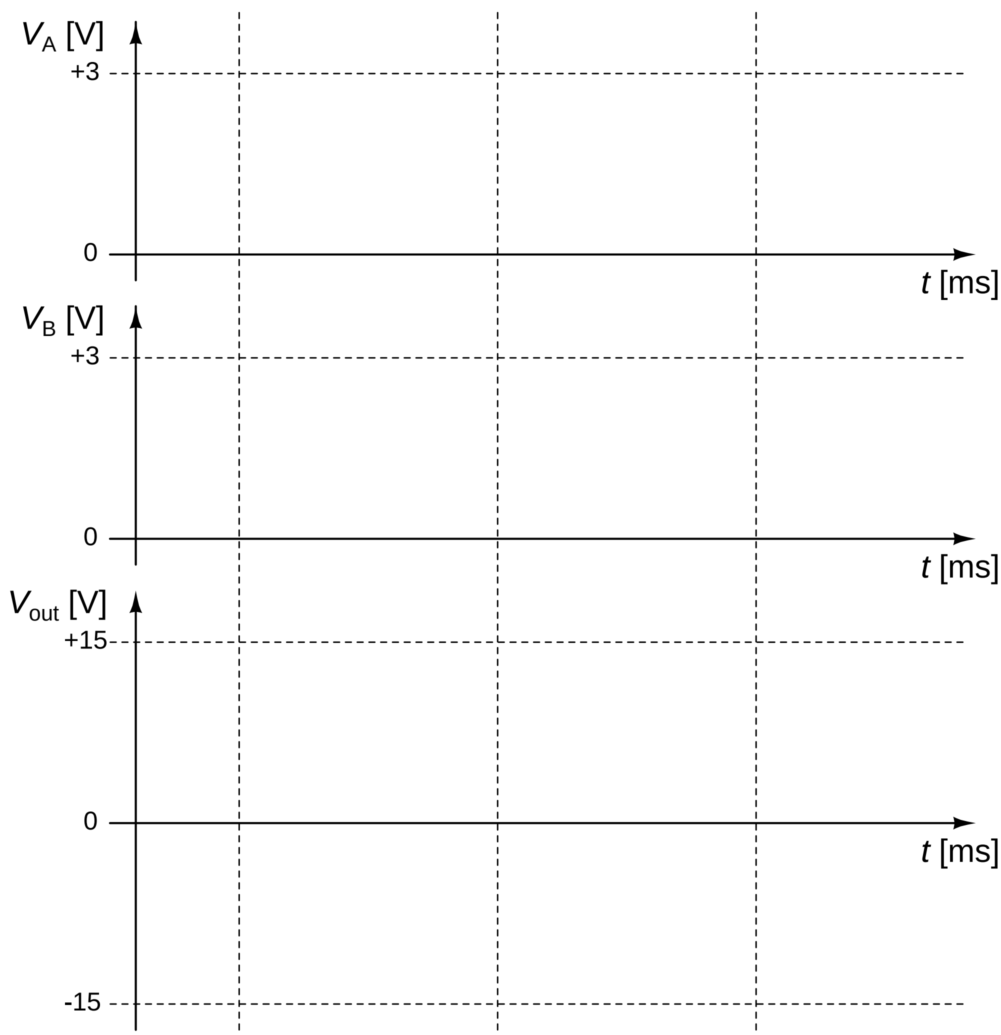
(c) [5 pts] What is the output impedance at the V_{out} node?

2. **[35 pts]** A deep-brain stimulation (DBS) circuit is shown below. All active components are ideal. The 555 timer IC and the NOR logic gate operate from a +3V single supply, while the opamp operates from a +15V/-15V dual supply. The CTRL control input is logic low (0 V) by default. The values for the passive components are $R_1 = 572\,\mathrm{k}\Omega$, $R_2 = 286\,\mathrm{k}\Omega$, $R_3 = 100\,\mathrm{k}\Omega$, $R_4 = 300\,\mathrm{k}\Omega$, $R_5 = 0$, and $C = 10\,\mathrm{nF}$. You may also find these 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) [25 pts] Sketch the waveforms for the voltages V_A, V_B and V_{out} on the diagrams on the next page. Ignore any initial transients, and assume that the circuit has been running forever such that the origin $t = 0$ on the time axis is arbitrary. Show your work below.


V_A [V]
+3
0
t [ms]
V_B [V]
+3
0
t [ms]
V_{out} [V]
+15
0
t [ms]
-15

(b) [5 pts] What purpose does the control input CTRL serve in the biomedical application? Explain.

(c) [5 pts] Does the output voltage V_{out} depend on the value of the resistance R_5? What purpose does a large R_5 serve in the biomedical application?

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

(a) [4 pts] The output V_{out} of the circuit at right (with an ideal LM311) goes high when the input V_{in} goes:

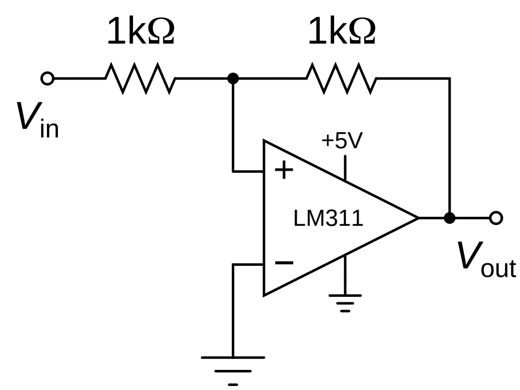
i. below 0

ii. above 0

iii. below +2.5V

iv. above +2.5V

v. below -5V



(b) [4 pts] An ideal transformer:

i. has zero output impedance

ii. has infinite input impedance

iii. converts magnetic to electrostatic energy

iv. shares all magnetic flux between input and output coils

v. has mutual inductance larger than either input and output inductances

(c) [4 pts] At very low current the electrode shown on the right has:

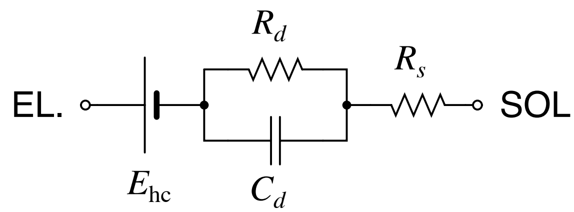
i. infinite impedance

ii. zero impedance

iii. voltage near the half-cell potential

iv. zero voltage

v. zero charge



(d) [1 pt ea.] Indicate for each statement below whether it is true or false:

i. **TRUE / FALSE**: Nernst potentials of ion types in live cells are actively maintained by ion pumps that continuously restore concentration gradients across the membrane.

ii. **TRUE / FALSE**: ECoG offers higher spatial and temporal resolution in resolving brain acitivty than EEG.

iii. **TRUE / FALSE**: EMG activity can be observed anywhere on the body.

iv. **TRUE / FALSE**: ERG is a measure of eye blink activity contaminating the EEG.

v. **TRUE / FALSE**: A dipole consists of a pair of monopoles of same magnitude and opposing polarity.

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

vii. **TRUE / FALSE**: At thermal equilibrium the doublelayer charge across the membrane is zero on average.

viii. **TRUE / FALSE**: Non-polarizable electrodes pass electrical current in either direction.

4. **[20 pts]** Consider two identical electrodes inserted in a Petri dish containing a biological cell culture preparation at room temperature. The cells are in a physiological saline environment of 0.15 mol/L NaCl in distilled water. Assume the cells are impermeable to K^+ and any other ion types except Na^+ and Cl^-. The GHK equation is:

$$V_m = \frac{RT}{F} \ln(10) \log_{10} \left(\frac{P_{\text{Na}}[\text{Na}^+]_o + P_{\text{K}}[\text{K}^+]_o + P_{\text{Cl}}[\text{Cl}^-]_i}{P_{\text{Na}}[\text{Na}^+]_i + P_{\text{K}}[\text{K}^+]_i + P_{\text{Cl}}[\text{Cl}^-]_o} \right)$$

and at room temperature $RT/F \ln(10) \approx 60$ mV.

(a) [5 pts] Assume both electrodes are in the extracellular saline environment, without penetrating any cell. What voltage do you expect to measure by a voltmeter with infinite input impedance between the electrodes, and why?

(b) [15 pts] Now one of the two electrodes is inserted in one of the cells in the culture. When a pharmacological agent is introduced to block all sodium channels, the voltage measured between this electrode and the other electrode remaining in the saline environment is $V_{cell} - V_{saline} = -60$ mV. What does that tell about Nernst potentials of the cell, and ion concentrations inside the cell? Explain.