BENG 186B Winter 2015

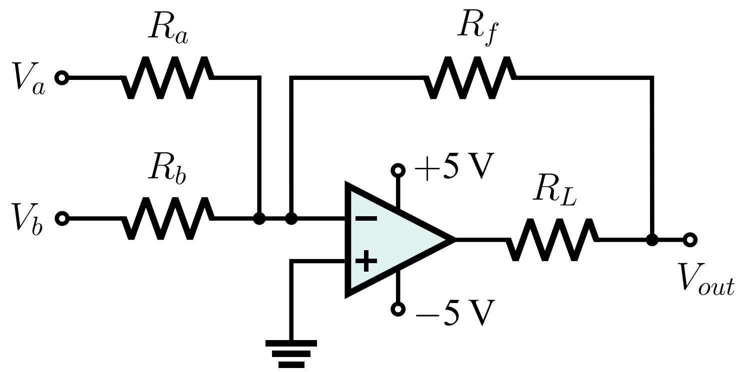
Quiz 2

Wednesday, February 11, 2015

Last Name, First Name: ____

- This quiz is closed book and closed notes. You may use a calculator for algebra and arithmetic.
- This quiz has 10 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. **[30 pts]** Consider the following circuit:



(a) Assume the operational amplifier is ideal and unsaturated. Derive **from first principles** an expression for V_{out} in terms of V_a and V_b.

(b) Does the V_{out} expression from part (a) depend on R_L?

(c) What is the maximum current drawn from the operational amplifier during a short circuit at the output, $V_{out} = 0$? What function does R_L serve? *Hint:* Consider the voltage supplies of the operational amplifier.

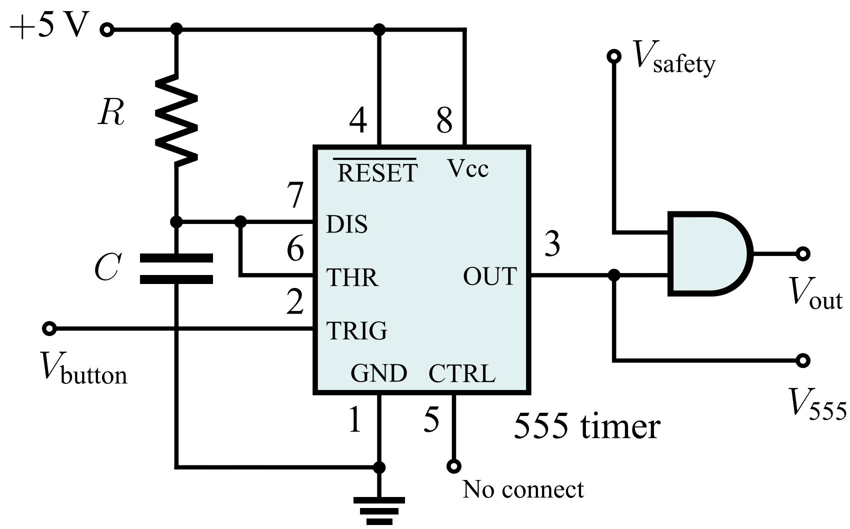
(d) What are the input impedances of the two inputs?

(e) You can use the above circuit to produce an inverted average of the inputs:

$$V_{out} = -\frac{V_a + V_b}{2}$$

Based on the V_{out} expression from part (a), what values for R_a, R_b, and R_f could you use to achieve this?

2. **[25 pts]** The circuit shown below controls an automatic syringe pump. It is designed to deliver a fixed amount of fluid in response to each press of a button. The pump motor is controlled via V_{out} and can deliver 1 mL of fluid per second. The pump includes a "dead–man's" switch for safety purposes.

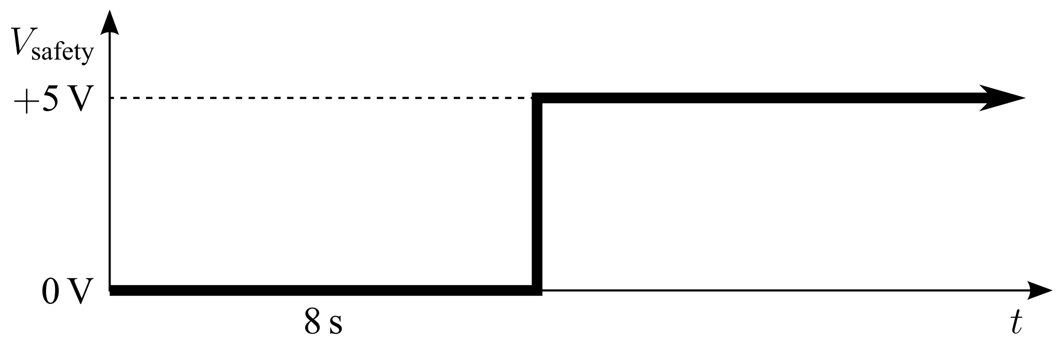


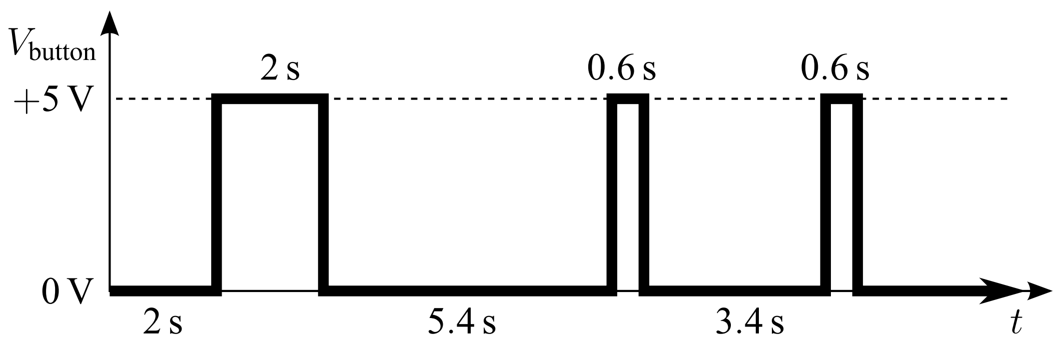
You may find these equations useful ($\ln(3) \approx 1.1$ and $\ln(2) \approx 0.7$):

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

(a) What numerical values for R and C could you use so that the syringe pump delivers 2 mL of fluid per button press?

(b) Shown below are waveforms for V_{button} and V_{safety}. Given these inputs, draw **and fully label** the output waveforms for V_{555} and V_{out}.

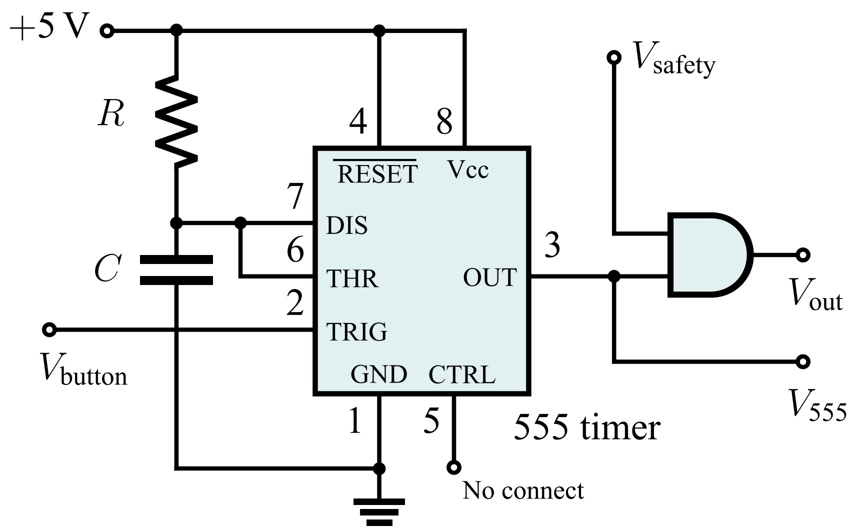




(c) The syringe itself contains a sensor with a voltage output that varies linearly with respect to fluid volume. In particular, the sensor outputs:

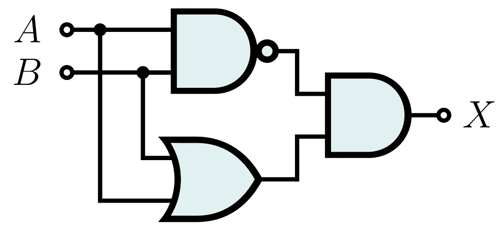
- 0 V when the syringe is completely empty; and
- 5 V when the syringe is completely full.

Modify the circuit, copied below, so that the pump is disabled when the syringe is less than 10 % full. **Be sure to label all components and their values, if applicable**. You may directly annotate changes on the copy below.



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

(a) [4 pts] The logic circuit shown on the right is equivalent to:



i. $X = \text{AND}(A, B)$

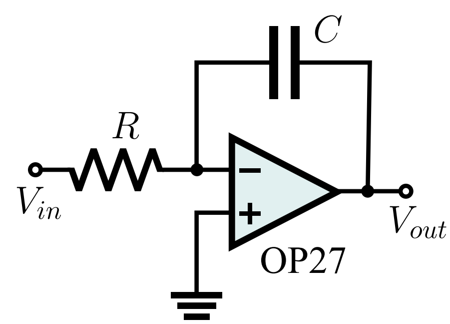
ii. $X = \text{OR}(A, B)$

iii. $X = \text{XOR}(A, B)$

iv. $X = \text{NAND}(A, B)$

v. none of the above

(b) [4 pts] The circuit shown on the right implements what function?



i. non-inverting low-pass filter

ii. inverting high-pass filter

iii. inverting integrator

iv. non-inverting differentiator

v. none of the above

(c) [4 pts] The following takes place at the electrode-electrolyte interface for electrochemical transduction:

i. negative basic molecules react non-reversibly with positive acidic molecules on the electrode

ii. anions from the electrolytes switch places with the cations on the electrode

iii. water cleaves electrons off the electrode and reacts with the resulting cations

iv. cations flow across the electrode-electrolyte interface while electrons flow in the electrode in the opposite direction

v. none of the above

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

i. **TRUE / FALSE**: During depolarization the net charge inside the cell shifts from negative to positive.

ii. **TRUE / FALSE**: The SA node depolarizes the right atrium which in turn triggers the AV node to depolarize the ventricles.

iii. **TRUE / FALSE**: The T wave represents ventrical depolarization.

iv. **TRUE / FALSE**: Skin impedance and noise from skeletal muscles are significant issues when non-invasively measuring signals farther inside the body.

v. **TRUE / FALSE**: Electroretinograms (ERG) involve a series of high-constrast images shown to patients to help measure their retinal response.

vi. **TRUE / FALSE**: An Ag electrode injecting a positive current into chlorine electrolyte causes deposition of an AgCl layer.

vii. **TRUE / FALSE**: Cell permeability to an ion is relevant when using the GHK equation, but the individual Nernst can be determined even if the cell is not permeable to the ion type.

viii. **TRUE / FALSE**: Ion pumps in the membrane are constantly keeping the Nernst potential fixed at the resting state.

4. **[25 pts]** A typical mammalian cell contains the following ion concentrations:

Ionic species	Concentration (mM) Intracellular	Concentration (mM) Extracellular
K^+	400	20
Na^+	50	400
Cl^-	40	550
Ca^{2+}	0.0001	5

(a) What is the Nernst potential for each ionic species?

(b) Given these relative permeabilities and the GHK equation:

$$P_{\mathrm{K}} = 1 \quad P_{\mathrm{Na}} = 0.01 \quad P_{\mathrm{Cl}} = 2 \quad P_{\mathrm{Ca}} = 0$$

$$V_m = 60\,\mathrm{mV} \times \log\left(\frac{P_{\mathrm{Na}}[\mathrm{Na}^+]_o + P_{\mathrm{K}}[\mathrm{K}^+]_o + P_{\mathrm{Cl}}[\mathrm{Cl}^-]_i}{P_{\mathrm{Na}}[\mathrm{Na}^+]_i + P_{\mathrm{K}}[\mathrm{K}^+]_i + P_{\mathrm{Cl}}[\mathrm{Cl}^-]_o}\right)$$

What is the equilibrium membrane potential V_m of the cell?

(c) Assume the capacitance of the cell membrane is 1 μF/cm^2, and that you have a spherical cell 10 μm in diameter. Calculate how many K^+ ions must cross the membrane to change itspotential by 10 mV. *Hint:* The charge of a proton is 1.6×10^{-19} C.