

EECS 16A
Spring 2019

Designing Information Devices and Systems I

Midterm 2

Exam Location: Cory 521 (DSP)

PRINT your student ID: _____

PRINT AND SIGN your name: _____, _____
(last name) (first name) (signature)

PRINT time of your Monday section and the GSI's name: _____

PRINT time of your Wednesday section and the GSI's name: _____

Name and SID of the person to your left: _____

Name and SID of the person to your right: _____

Name and SID of the person in front of you: _____

Name and SID of the person behind you: _____

1. How is your semester so far? (1 point)

[Empty rectangular box for answer]

2. Do you have any summer plans? (1 point)

[Empty rectangular box for answer]

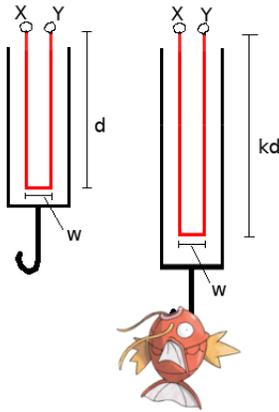
Do not turn this page until the proctor tells you to do so. You may work on the questions above.

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3. Fisherman Friend (10 points)



My fisherman friend wants to make an automatic fishing rod. First, he wants to create a circuit that can sense when a fish is biting. He has already made a special stretchy fishing hook, shown on the left.

The entire apparatus is stretchy, and the interior string is a resistor with terminals X and Y and resistivity ρ . Without a fish on it, the string has cross-sectional area A and length $2d$ (You can assume that the width w is negligible, or $w \ll d$).

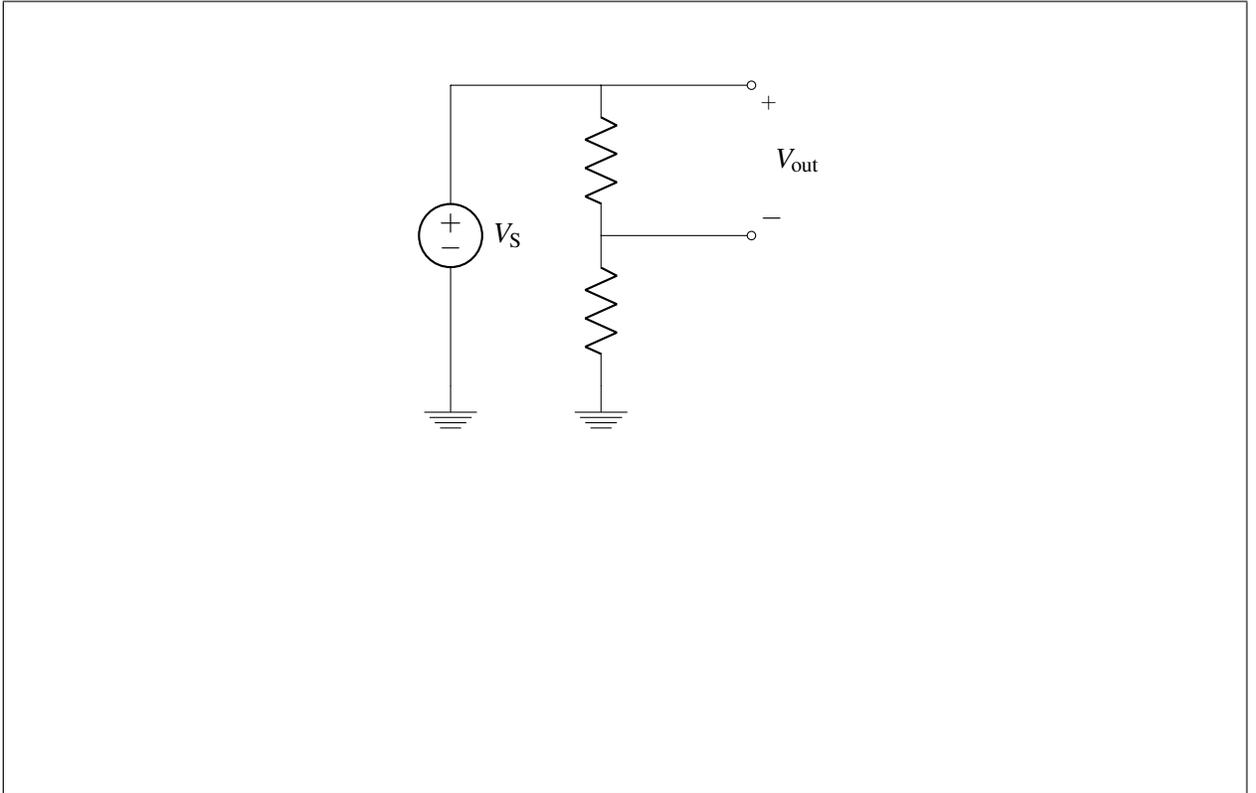
When a fish bites, the length of the string stretches by a factor of $k > 1$, but the volume of the string remains constant. The resistivity ρ also remains constant.

My fisherman friend wants to know what kind of circuit he should attach to X and Y . Please help him.

- (a) (4 points) If the resistor has resistance R without a fish on it, find the resistance when a fish bites.

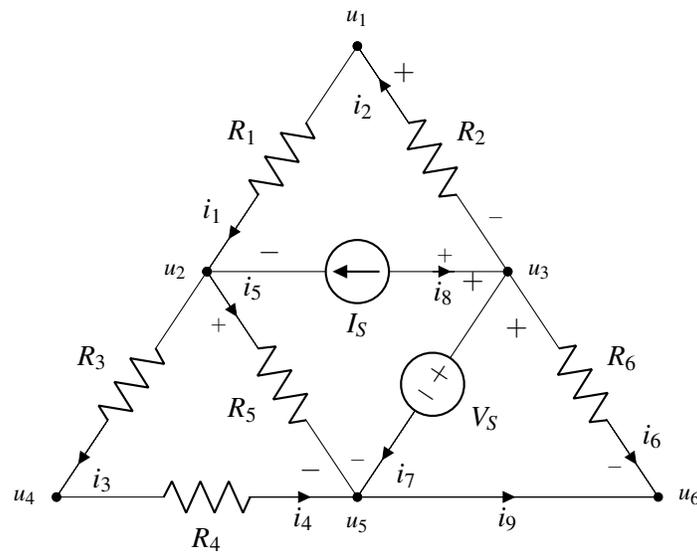
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- (b) (6 points) My fisherman friend has a voltmeter. He also has a voltage source and an extra non-stretchy resistor. He has an idea of what kind of circuit to use, which is shown below, where the two nodes across which he measures the voltage is labeled by V_{out} . But he's not sure which of the two resistors should be stretchy. Can you label the normal resistor by R_{normal} and the stretchy resistor by R_{stretch} such that V_{out} **increases** when a fish bites? Derive an expression for V_{out} to justify your answer.



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4. It's a Triforce! (10 points)



(a) (3 points) Which of the elements listed below have current-voltage labeling that violates Passive Sign Convention? Fill in the circle on the left of all the correct answer(s).

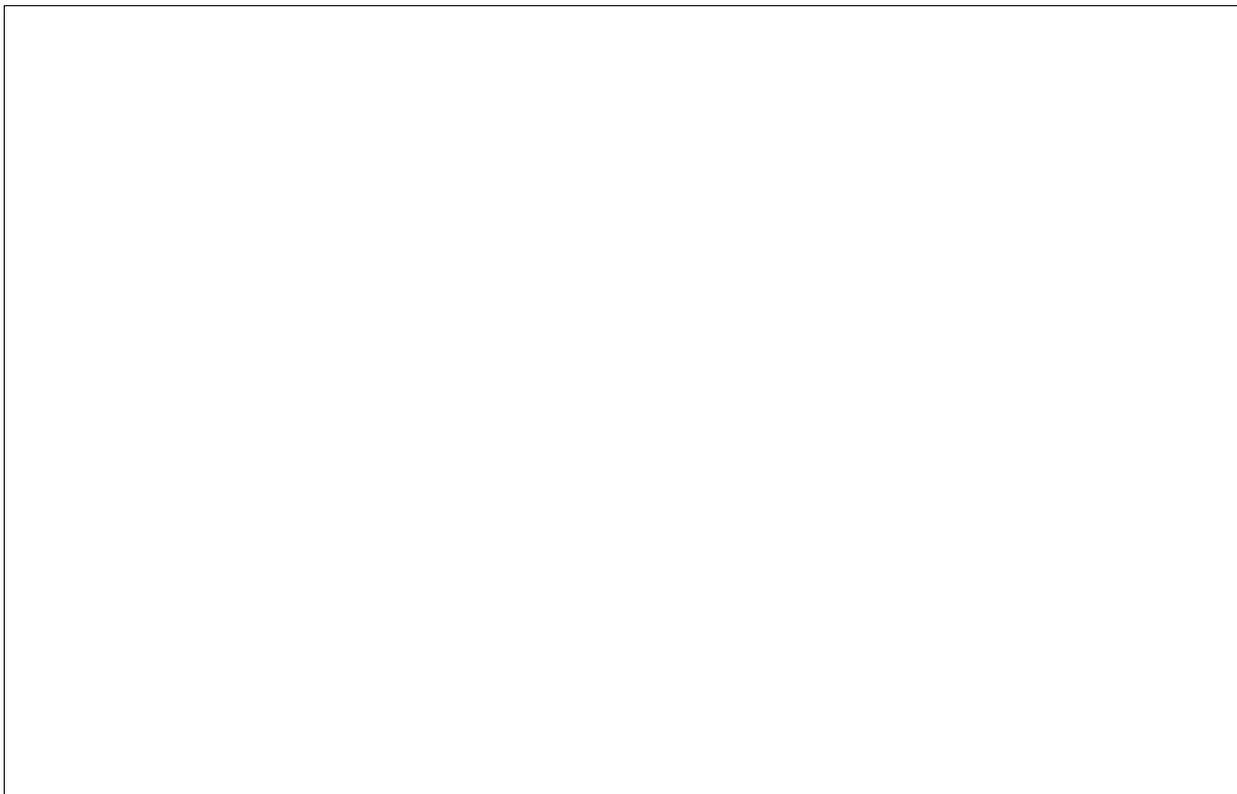
I_s V_s R_2 R_5 R_6

(b) (3 points) There is a subset of nodes in the given circuit that are redundant. Fill in the circles on the left of all the nodes that can be merged into a single node.

u_1 u_2 u_4 u_5 u_6

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- (c) (4 points) Write the KCL equation for node u_2 in terms of the node potentials and other circuit elements.



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5. You Can't Just Beam Yourself Up (20 points)

You got stranded on Bohemian Junkheap while on your way to planet Risa for your spring break vacation. Now you need to scavenge for equipment parts to contact the rest of your friends on Risa.

You found a signal encoder, which can be modeled as a 2-terminal network. Then you programmed it to send out the following bits as a train of voltage pulses: {1 1 0 1 0}. You did the following measurements to test its output, as shown in Figures (5.1) and (5.2):

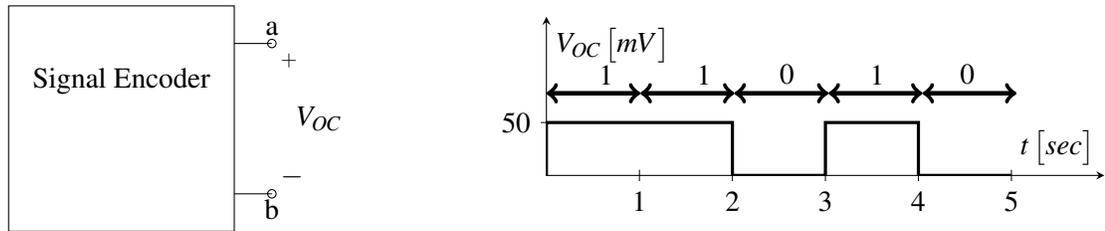


Figure 5.1: Measurement in open-circuit condition

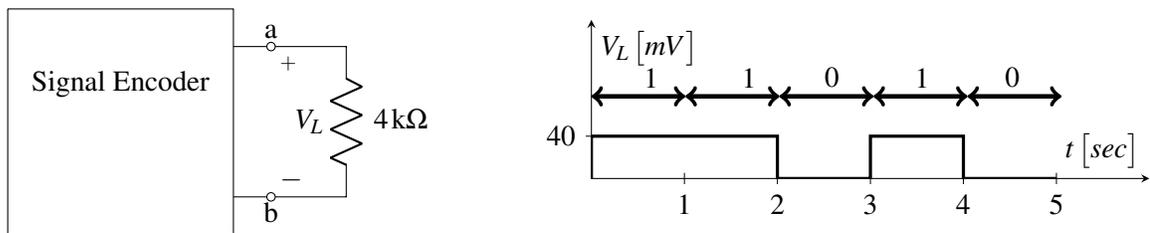
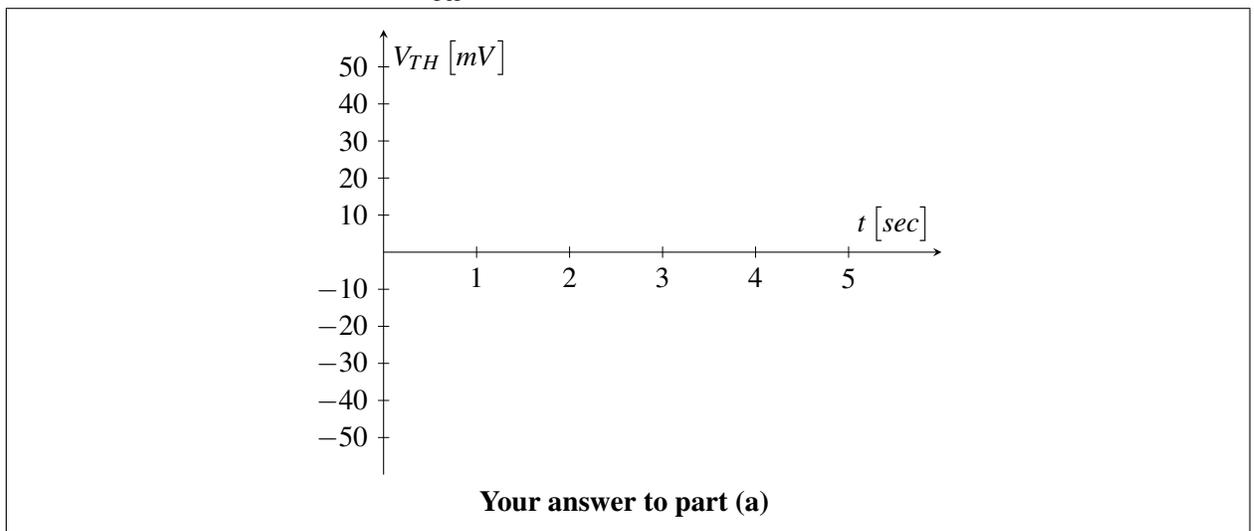


Figure 5.2: Measurement with resistive load

- (a) (10 points) Find the Thévenin equivalent circuit of the signal encoder, i.e. **plot V_{TH} below as a function of time and find the value of R_{TH} .**



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- (b) (10 points) Since the signal encoder output is not very strong, you need an amplifier to boost the output voltage. Luckily your friend Urmita arrives through the Astral Gate with an amplifier, which can be modeled and connected as shown in Figure 5.3.

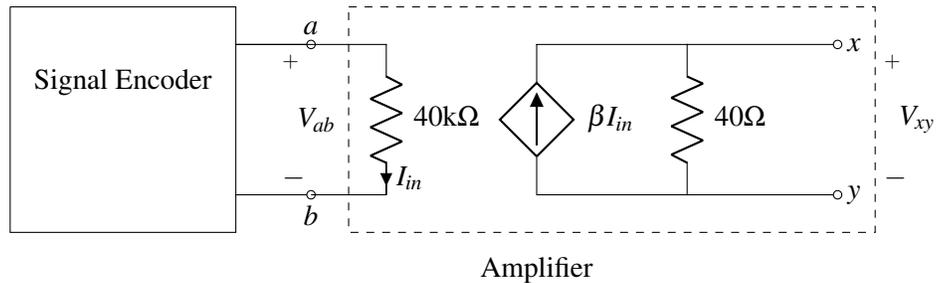
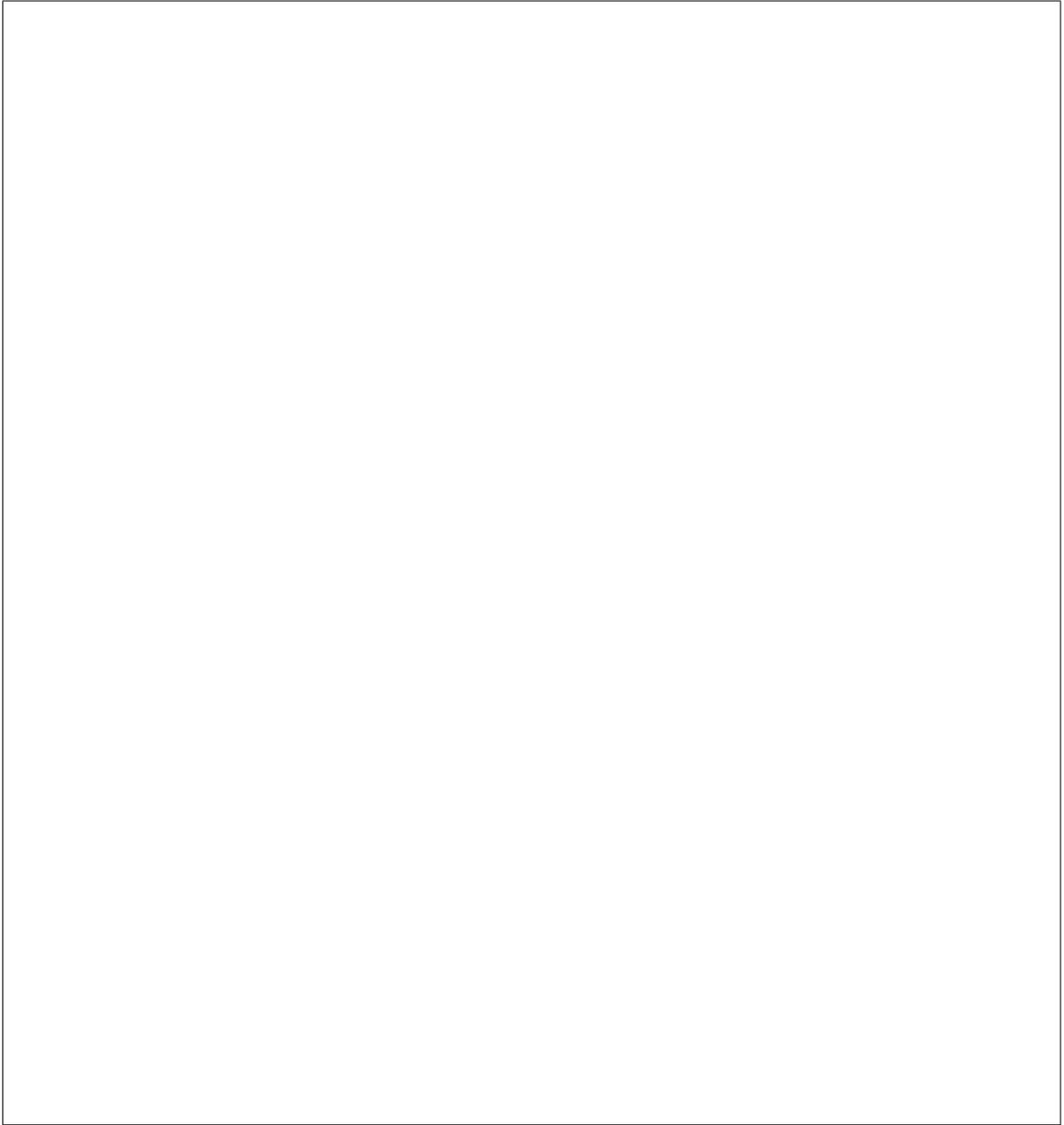


Figure 5.3: Encoder connected to an amplifier

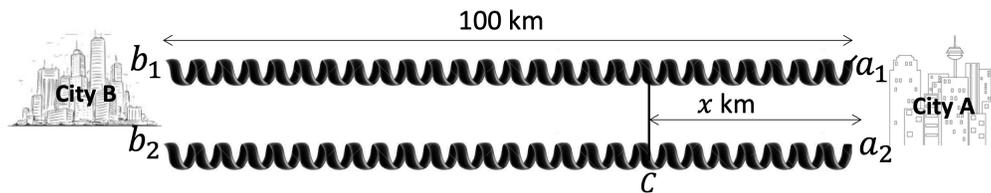
You need to adjust the value of β for the dependent source, so that the amplifier has a gain of 100, i.e. $V_{xy} = 100V_{ab}$. **Find the value of β .**

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6. Telephone cable (15 points)

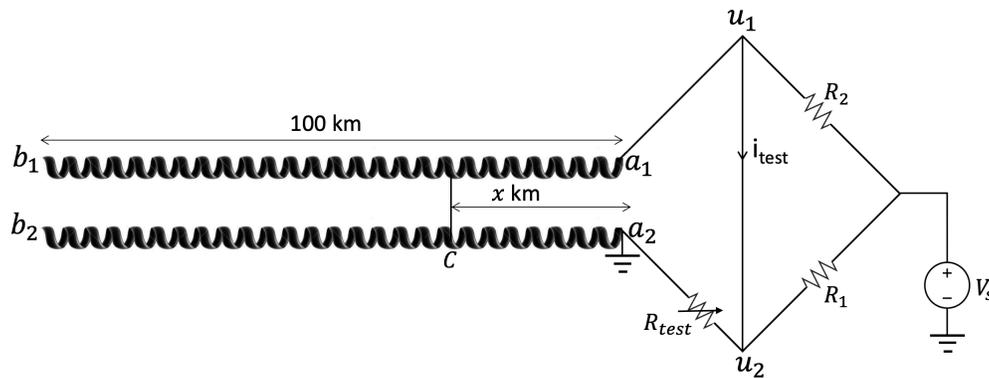


The telephone cable between city **A** and city **B** is broken at an unknown location **C**, which means the broken part of the cable is shorted at the location **C**. City **A** and city **B** are 100 km apart. The telephone cable resistance is $6 \Omega/\text{km}$ for a single cable. Let's help the technician to find out where the location **C** is.

- (a) (5 points) To build a model of the telephone wire, we can regard the telephone cable from a_2 to **C** as a single resistor R_{a_2C} . The distance between a_2 and **C** is x km. What's the resistance of R_{a_2C} ?

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- (b) (10 points) To figure out where the location **C** is, the technician in city **A** attaches a testing circuit between a_1 and a_2 shown in the figure below, where $R_1 = R_2 = 1000\Omega$. R_{test} is an adjustable resistor and its resistance can be adjusted between $100\Omega \sim 1000\Omega$. The technician measures the current i_{test} while changing R_{test} .

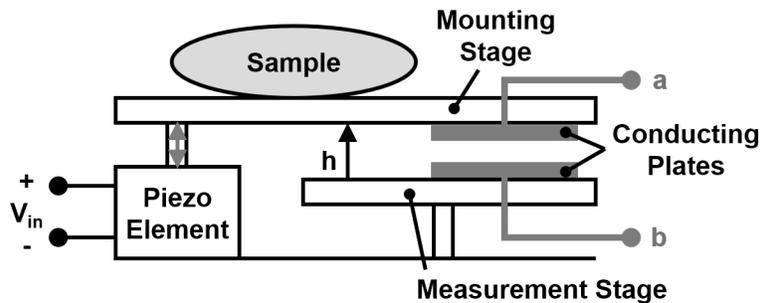


When the technician measures $i_{test} = 0$, the adjustable resistor $R_{test} = 480\Omega$. Use this information to help the technician find out where the location **C** is (solve for x)?

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7. Piezo positioner (15 Points)

A Piezo positioner is a device often used to precisely control the position of mounting stages - for example in microscopes. The overall structure of a Piezo positioner is shown below.



Using this instrument, you can adjust the height of the mounting stage h by changing the input voltage (V_{in}), utilizing a special component called “piezoelectric element”. The resulting relationship between V_{in} and h is given as follows:

$$h = \alpha_0 V_{in} + h_0.$$

In other words, h is at some default position h_0 when there’s no input, and the stage rises as we increase V_{in} .

In addition, the Piezo positioner has other parts to make it possible for you to **monitor** the height of the mounting stage. This monitoring system also has two conductive plates of the area A , each attached to the mounting stage and the measurement stage. You can connect any circuit you may have to these plates through the electrode **a** and **b**. Note that two plates form a capacitor. Assume that the space between two plates is filled with the air, whose permittivity is given as ϵ_0 . Ignore the thickness of the stages as well as the conducting plates.

- (a) (5 points) The initial V_{in} is 0 V. Let’s say now you want to **raise** the location of the sample by Δh . What is the new V_{in} ? Also, express the capacitance between a and b after the movement as a function of given parameters.

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(b) (10 points) Now you notice that it is possible to monitor the location of the mounting stage by measuring C_{ab} . To measure this capacitance, your friend proposed the following method:

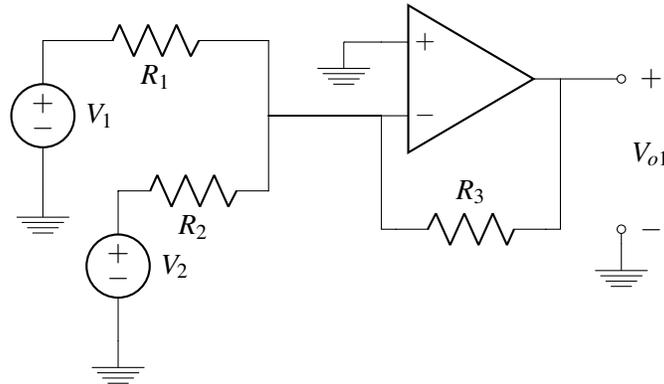
- Phase 0: short the C_{ab} to make the initial charge 0.
- Phase 1: connect a current source I_S to charge C_{ab} exactly for T seconds
- Phase 2: disconnect the current source, and then measure the voltage between a and b.

Calculate the voltage between a and b at the end of Phase 2, in terms of C_{ab} .

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8. Swimming Pool Pressure Sensors (20 points)

A swimming pool has two pressure sensors that output voltage measurements that scale linearly with the amounts of pressure measured by the sensors. One sensor measures the pressure at the top of the swimming pool, which is the air pressure of the environment, and outputs V_1 . The second sensor measures only the pressure exerted by the water in the swimming pool, and outputs V_2 .



The pool manager would like to have the above op amp circuit output V_{o1} to continuously monitor the pressure the bottom of the pool would sense (i.e. the circuit that sums the outputs of both sensors).

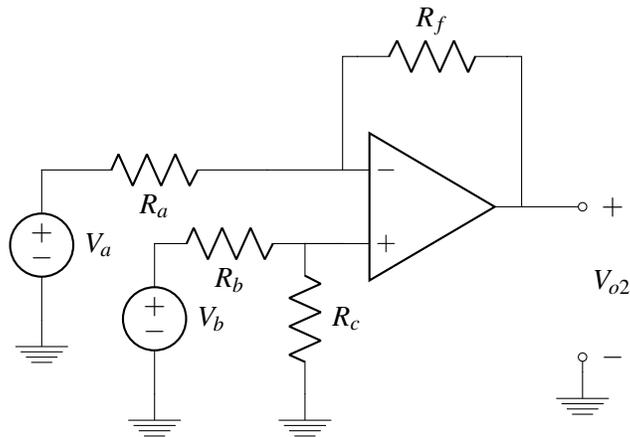
- (a) (5 points) In terms of V_1 , V_2 , R_1 , R_2 , and R_3 , what is V_{o1} ? Mathematically justify your answer, i.e. perform circuit analysis to find V_{o1} .

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- (b) (3 points) The pool manager gives you an inverting amplifier that negates V_{o1} , the output of the above circuit (i.e. the output of the inverting amplifier is $-V_{o1}$). What condition(s) do you need on R_1 , R_2 , and R_3 (i.e. what equation(s) involving R_1 , R_2 , and R_3 must be satisfied) so that the output of the inverting amplifier is $-V_{o1} = V_1 + V_2$?

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One day, a janitor accidentally breaks the screen of the second sensor while cleaning, and the value of V_2 cannot be read from the sensor anymore. Luckily, the circuit above still functions correctly and $-V_{o1}$, the output of the inverting amplifier, still measures the sum of the two sensors (i.e. $V_1 + V_2$). The pool manager asks you to use the below circuit to retrieve V_2 from V_{o1} and V_1 .



- (c) (7 points) What is V_{o2} in terms of V_a , V_b , R_a , R_b , R_c , and R_f ? Mathematically justify your answer, i.e. perform circuit analysis to find V_{o2} .

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- (d) (3 points) What condition(s) do you need on R_a , R_b , R_c , and R_f (i.e. what equation(s) involving R_a , R_b , R_c , and R_f must be satisfied) such that the above circuit performs a simple subtraction operation, i.e. $V_{o2} = V_b - V_a$?

- (e) (2 points) The manager would now like to recover V_2 (the output of the second sensor) from $-V_{o1}$ (the output of the inverting amplifier) **and** V_1 (the output of the first sensor). What must V_a and V_b be in the above circuit to have $V_{o2} = V_b - V_a = V_2$, the output of the second sensor? You do not have the tools to multiply any sensor output, but you have $-V_{o1}$ and V_1 available for use.

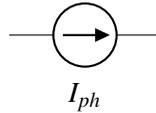
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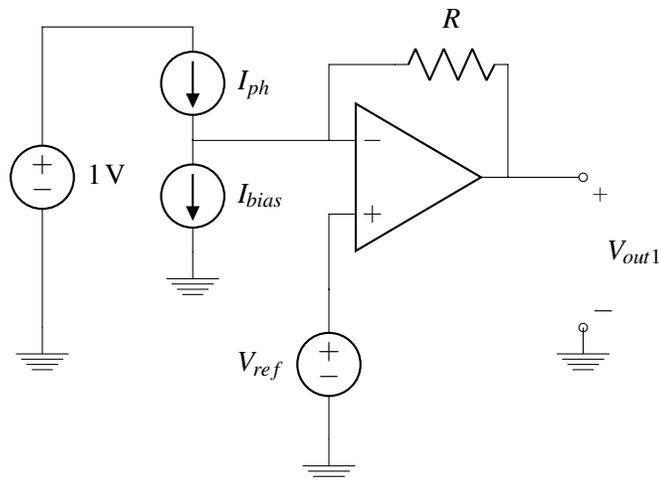
9. Communicating with Light (15 points)

After finishing EE16A, you got the opportunity to work with Professor Vladimir. His group designs computer chips that communicate with light, and your job is to design the receiver. Your receiver connects to a photodetector, that can be modeled as current source.



When light is shining on the receiver, the current becomes $I_{ph} = 1 \mu\text{A}$. Otherwise, with no light shining on the receiver the current is $I_{ph} = 0\text{A}$. The circuit should output 0V to the processor when there is light shining on the receiver, and output 1V to the processor when there is no light shining on the receiver.

- (a) (10 Points) Your friend suggests the following circuit to turn the current into a voltage. Find the output voltage, V_{out} as a function of I_{ph} , and find a value of R such that the circuit outputs 0V when $I_{ph} = 1 \mu\text{A}$. $I_{bias} = 0.5 \mu\text{A}$ and $V_{ref} = 0.5\text{V}$. Show your work.



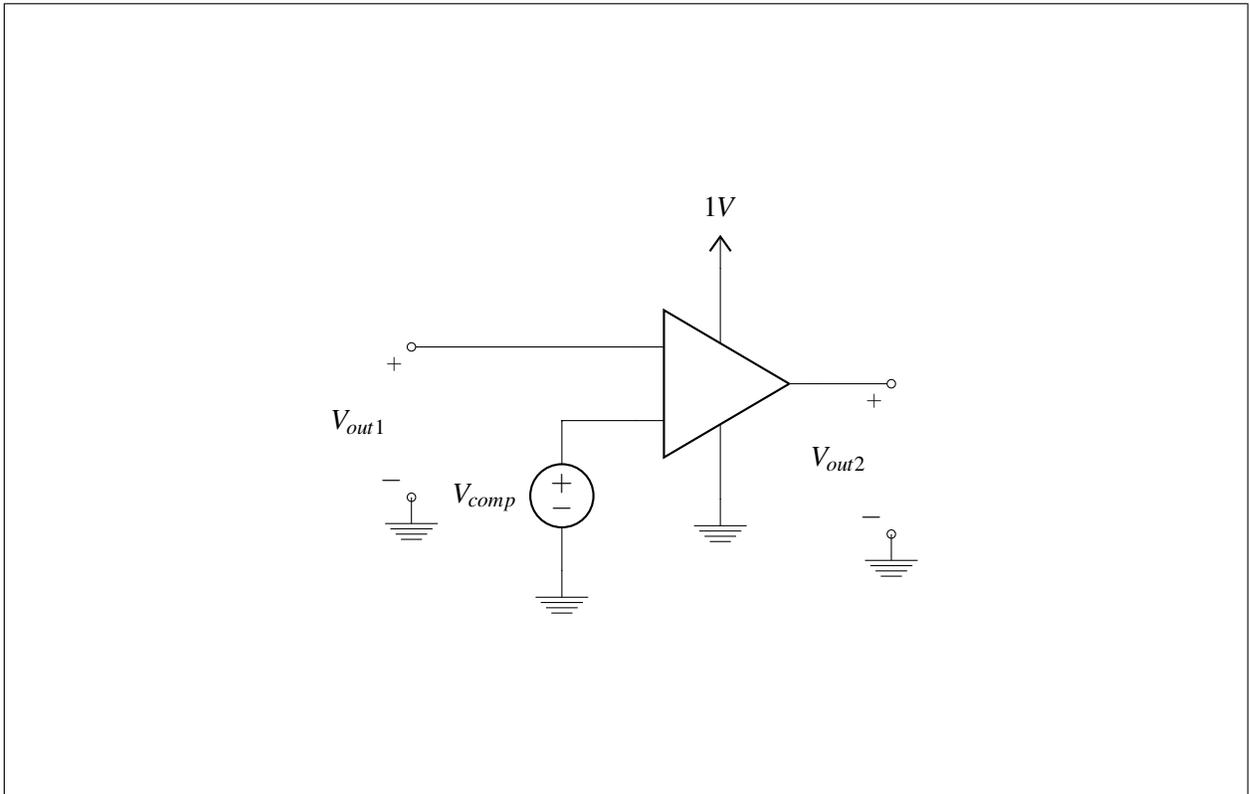
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- (b) (5 Points) After building the circuit and testing it, you find that I_{ph} varies as you get closer or further from light. This causes the output voltage of your circuit to not be precisely 0V or 1V.

However, the processor needs exactly 0V when light is shining, and 1V when no light is shining. Vlad advises you add a comparator to your design. Finish the circuit below by calculating the value of V_{comp} for the comparator. Also select the polarity of the comparator by drawing a + or - in corresponding boxes in the diagram below.



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Doodle page!

Draw us something if you want or give us suggestions, compliments, or complaints.
You can also use this page to report anything suspicious that you might have noticed.

Read the following instructions before the exam.

There are 9 problems of varying numbers of points. You have 120 minutes for the exam. The problems are of varying difficulty, so pace yourself accordingly and avoid spending too much time on any one question until you have gotten all of the other points you can.

There are 26 pages on the exam, so there should be 13 sheets of paper in the exam. The exam is printed double-sided. Do not forget the problems on the back sides of the pages! Notify a proctor immediately if a page is missing. **Do not tear out or remove any of the pages. Do not remove the exam from the exam room.**

No collaboration is allowed, and do not attempt to cheat in any way. Cheating will not be tolerated.

Write your student ID on each page before time is called. If a page is found without a student ID, we are not responsible for identifying the student who wrote that page.

You may consult ONE handwritten 8.5" × 11" note sheet (front and back). No phones, calculators, tablets, computers, other electronic devices, or scratch paper are allowed.

Please write your answers legibly in the boxed spaces provided on the exam. The space provided should be adequate. **If you still run out of space, please use a boxed space for another part of the same problem and clearly tell us in the original problem space where to look.**

In general, show all of your work in order to receive full credit.

Partial credit will be given for substantial progress on each problem.

If you need to use the restrooms during the exam, bring your student ID card, your phone, and your exam to a proctor. You can collect them once you return from the restrooms.

Our advice to you: if you can't solve the problem, state and solve a simpler one that captures at least some of its essence. You might get some partial credit, and more importantly, you will perhaps find yourself on a path to the solution.

Good luck!

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