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EECS 16A  
Fall 2018

Designing Information Devices and Systems I

Midterm 2

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Exam Location: Soda 373 (DSP)

PRINT your student ID: \_\_\_\_\_

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

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

PRINT the 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. What is one of your hobbies? (2 Points)**

**2. Tell us about something that makes you happy. (2 Points)**

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

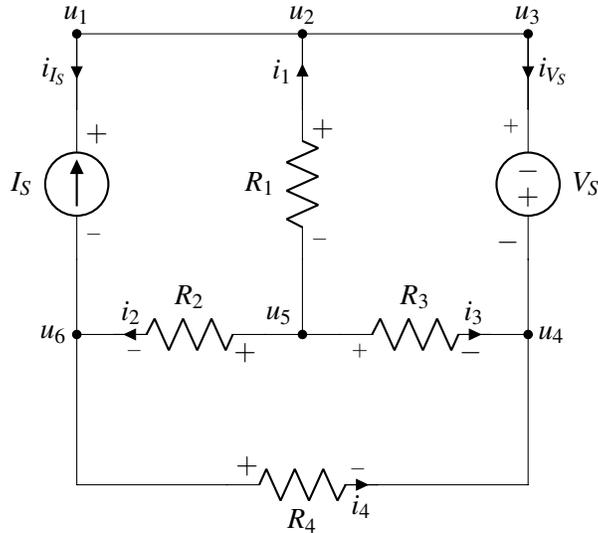
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### 3. Know Thy Nodes (10 points)

Refer to the circuit below for the entirety of this question.



- (a) (2 points) Which element(s) of the circuit have current-voltage labeling that violates Passive Sign Convention? Fill in the circle on the left of all the right answer(s).

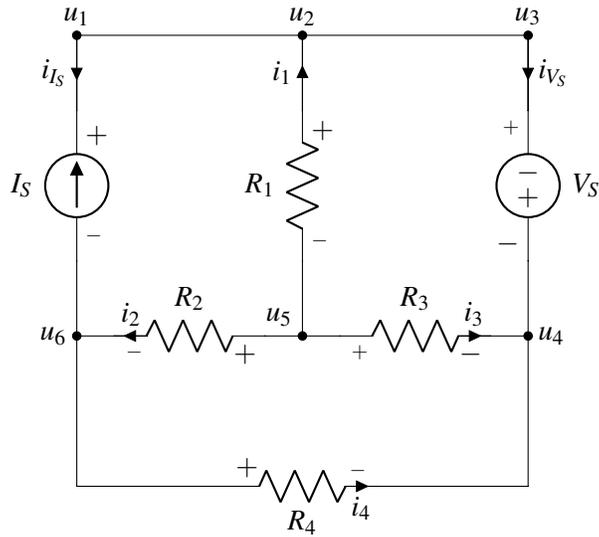
$I_s$      $V_s$      $R_1$      $R_2$      $R_3$      $R_4$

- (b) (2 points) There are more node labelings ( $u_1, \dots, u_6$ ) than necessary. There is one subset of node labelings that are all for the same node. Fill in the circles on the left of all nodes that can be merged into a single node.

$u_1$      $u_2$      $u_3$      $u_4$      $u_5$      $u_6$

- (c) (3 points) Write the equation for current-voltage relationship of  $R_3$  in terms of resistance, current and node potentials.

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 The circuit diagram is repeated here for your convenience.

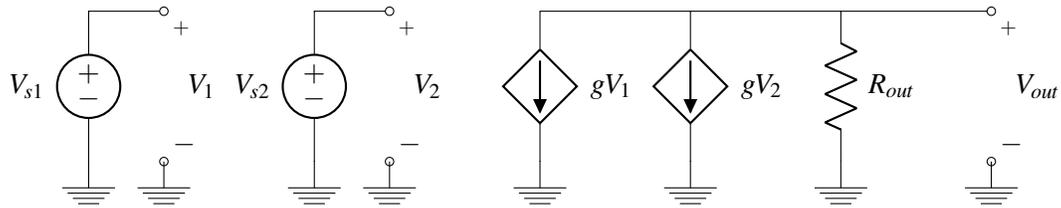


- (d) (3 points) Write the KCL equation for the currents associated with node  $u_6$  in terms of  $i_1, \dots, i_4, i_{I_S}$  and  $i_{V_S}$ .

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#### 4. A Tale of Two (Independent) Sources (12 points)

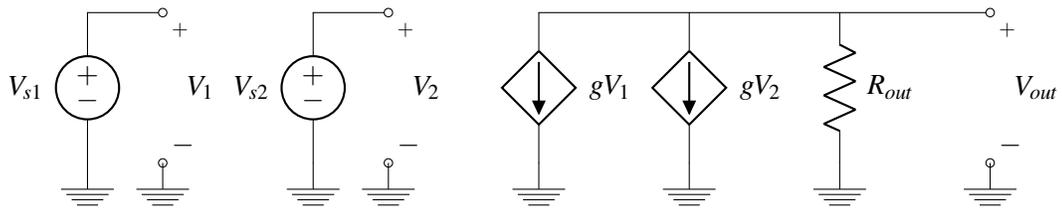
You are given the following circuit and asked what function it serves. We will use superposition to discover how the circuit can be used.  $g$  is a constant value with units  $[\frac{A}{V}]$ .



- (a) (3 points) First turn off  $V_{s2}$ . When only  $V_{s1}$  is active, let the output voltage  $= V_{out}$  be  $V_{out,1}$ . What is  $V_{out,1}$ ?

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The circuit is repeated here for your convenience.

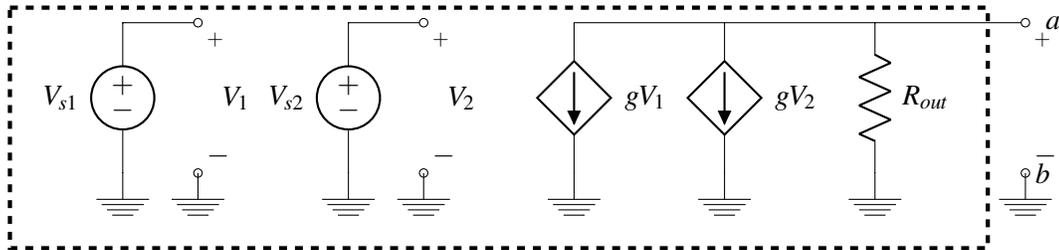


- (b) (3 points) Now turn off  $V_{s1}$ . When only  $V_{s2}$  is active, let the output voltage  $= V_{out}$  be  $V_{out,2}$ . What is  $V_{out,2}$ ?

- (c) (3 points) What is  $V_{out}$ , the output voltage, when both  $V_{s1}$  and  $V_{s2}$  are active? If  $g = \frac{1}{R_{out}}$ , then what is the function of the circuit in terms of  $V_{s1}$  and  $V_{s2}$ ?

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- (d) (3 points) Find the Thevenin equivalent of this circuit with respect to the output terminal, i.e. find the Thevenin equivalent of the boxed circuit with respect to terminals  $a$  and  $b$ , where  $g = \frac{1}{R_{out}}$ .



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### 5. Hot Dogs (14 points)

Michael and Alice are going on a picnic with Daisy the robot dog! But when they arrive at the park, a thunderstorm starts with lots of lightning... However, Daisy still wants to play in the park!

- (a) (6 points) We want to understand what will happen *if* Daisy is struck by lightning. A lightning bolt is represented with a voltage source of 1000 Volts (1kV) with reference to the Earth. The lightning travels through the ionized air ( $R_{Air} = 4$  kilo-Ohms ( $4\text{k}\Omega$ )), and through Daisy  $R_{Daisy} = 4\text{k}\Omega$  before reaching the ground. Daisy can withstand up to 10 Watts (W) of power before breakdown.

Using the circuit diagram in Figure 5.1, find if it is safe for Daisy to be struck by a lightning bolt. Justify your answer by showing your work!

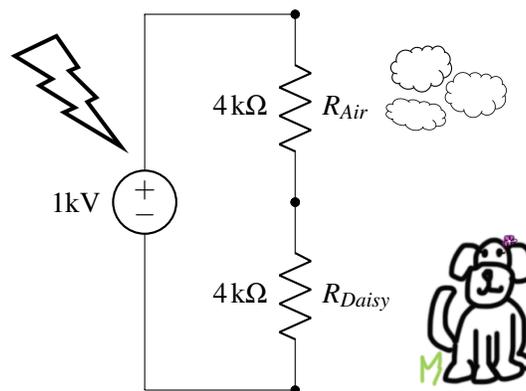


Figure 5.1: Circuit for Part (a)

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- (b) (8 points) Laura also brings along her dog, Elton, for the picnic. Elton has a resistance of  $R_{Elton} = 2\text{ k}\Omega$  and can withstand up to  $25\text{ W}$  of power. If Daisy and Elton hide together next to a tree of resistance  $R_{Tree} = 4\text{ k}\Omega$  as shown in the Figure 5.2, would either of the dogs withstand being struck by lightning? Show your work.

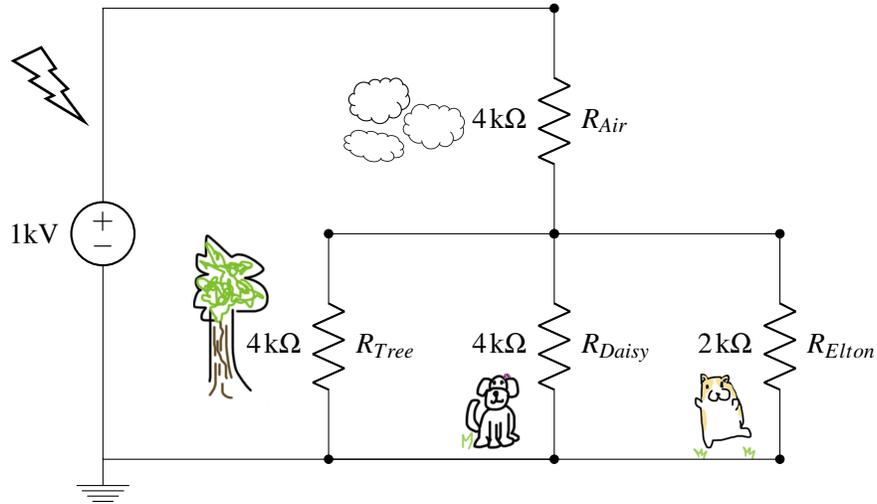
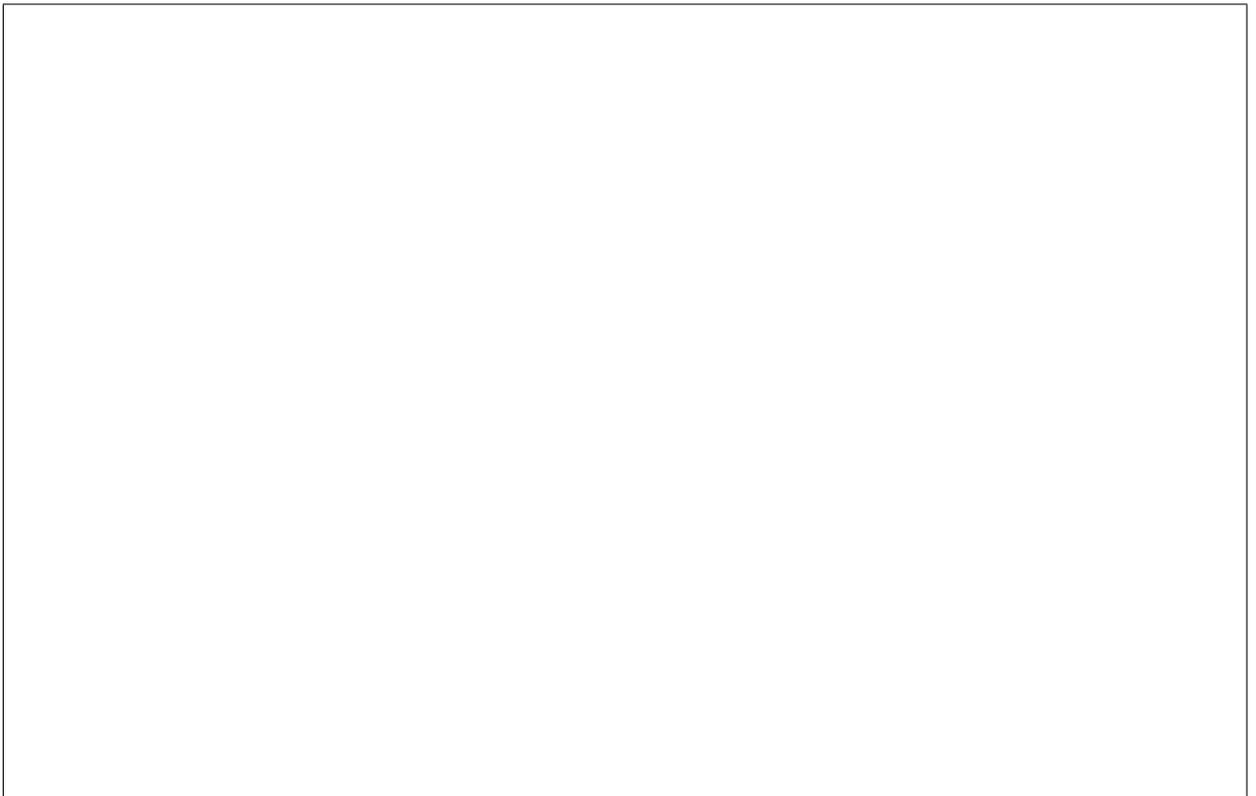


Figure 5.2: Circuit for Part (b)

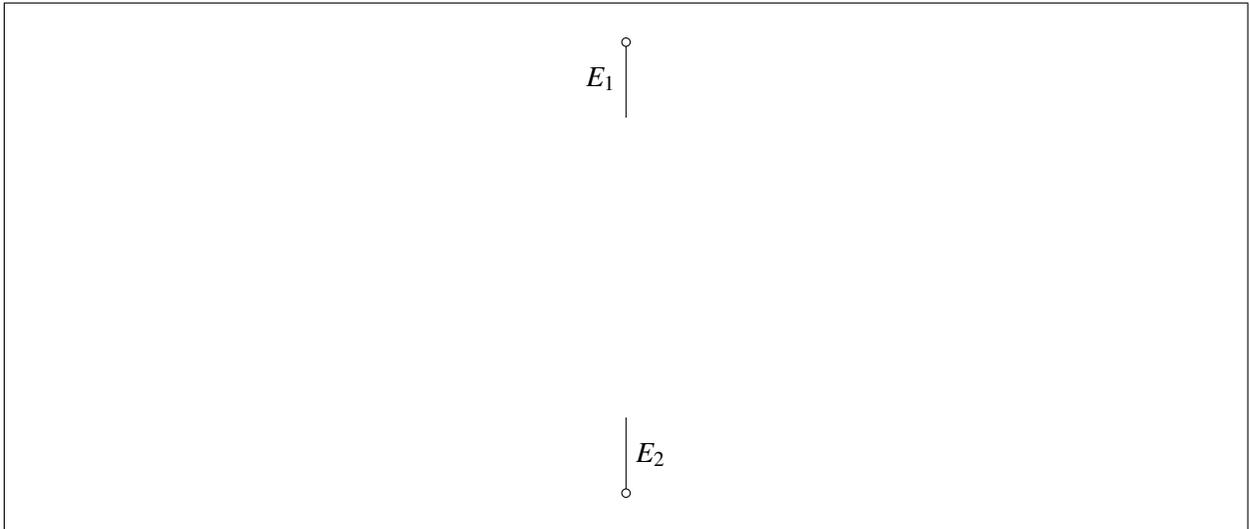




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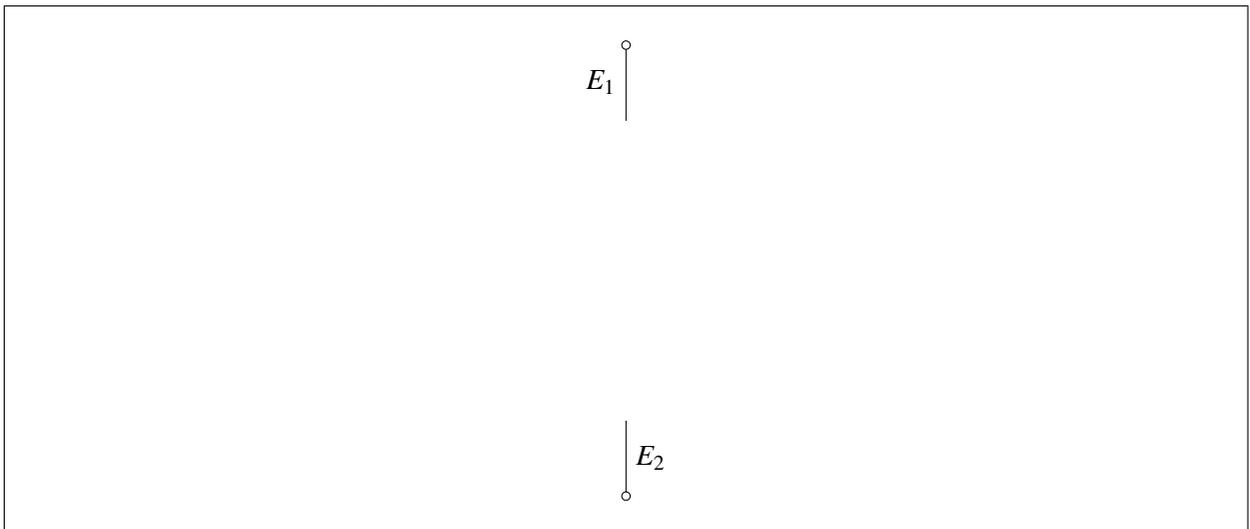
- (a) (2 points) Model the above configuration as a system of capacitors, **for when there is no touch** as shown in Figure 6.1a. Draw your circuit between the terminals  $E_1$  and  $E_2$  below.

You can draw a maximum of 3 capacitors to model this system. You **do not** have to label any properties of the capacitors yet.



- (b) (4 points) Model the configuration shown in Figure 6.1b, with the gap between the bars, as a system of capacitors, **for when there is a touch**. Draw your circuit between the terminals  $E_1$  and  $E_2$  below.

You can draw a maximum of 3 capacitors to model this system. You **do not** have to label any properties of the capacitors yet. **Hint:** *The finger is conductive. Consider it to be a node in your circuit diagram.*



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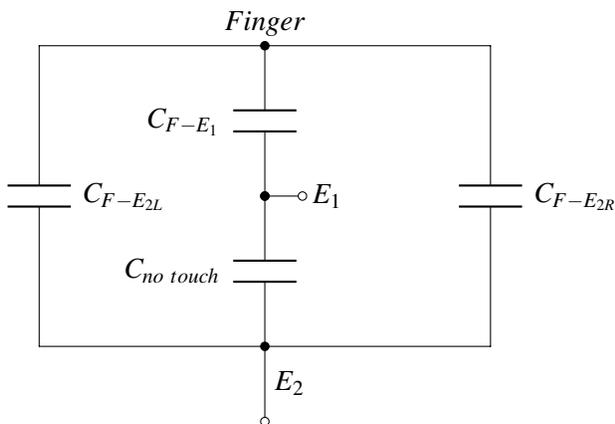
- (c) (5 points) You ask the pilots to run some experiments, and find out that the dielectric material between Bar1 and Bar2 has a permittivity  $\epsilon$  that starts at 12 F/mm and increases by 1 F/mm instantly every time the screen is touched. Using the variables  $d$ ,  $d_1$ ,  $d_2$ , and  $A$ , write the capacitance of the capacitor between Bar1 and Bar2 as a function of  $n$ , where  $n$  is the number of touches that have already happened (**there is no touch now**).

(Note: 12 Farads/mm is a very large permittivity. Normal permittivity values would be on the order of  $10^{-12}$  F/m.)

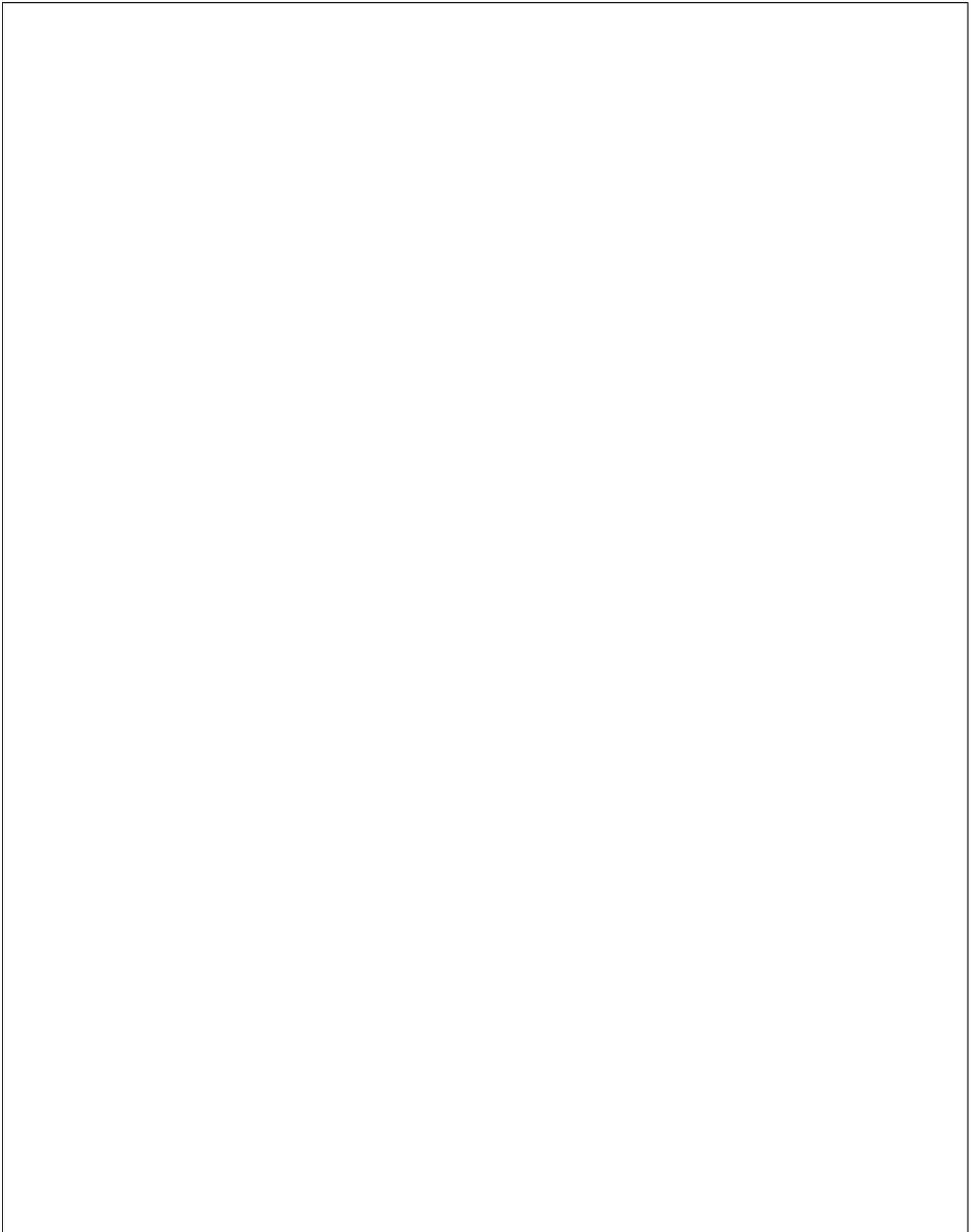
- (d) (7 points) **For the rest of this problem, use the circuit below to model the capacitive touchscreen.**

You are now given that  $C_{F-E_1} = 8F$ ,  $C_{F-E_{2L}} = 4F$ , and  $C_{F-E_{2R}} = 4F$ . Also,  $d = 2mm$ ,  $d_1 = 3mm$ ,  $d_2 = 7mm$ , and  $A = 4mm^2$ .

(Note:  $8F$  is a very large capacitance. Normal capacitance values would be on the order of nano-Farads, which are  $10^{-9}$  of a Farad.)



- Calculate the equivalent capacitance of the circuit between terminals  $E_1$  and  $E_2$  at the following times: (1) **during the  $n^{th}$  touch** (assume that the permittivity of faulty dielectric changes **instantly as the finger touches the screen.**) and (2) **after the  $n^{th}$  touch** (when the finger is not touching anymore.)
- The display cannot detect the touch if the difference between the touch and no-touch capacitances is smaller than 10% of the no-touch capacitance. Determine the **number of times the pilot can fire** before the display cannot detect the touch anymore. Show all your work.



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### 7. Noisy Parties (20 points)

To celebrate the (peaceful and very reasonable) end of the pizza-on-pineapple war, course staff decided to throw a party for the entire class! (Disclaimer: Not really) You and your friends want to take a picture to commemorate the night. In the imaging lab, you learned about how to make a camera with a single photodiode and a projector. Most modern cameras, however, have many photodiodes and do not need a sweeping light source like what you used in lab and need to work in non-ideal, non-laboratory conditions.

(a) (4 points) We can model a photodiode as a capacitor in parallel with a current source:

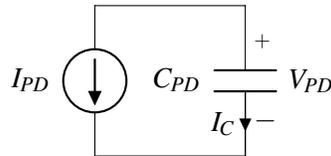


Figure 7.1: Photodiode circuit model

The current  $I_{PD}$  is related to the intensity of the light shining on the photodiode. Start with the following equations:

- $V_{PD}(t = 0) = V_{DD}$
- $I_C = C_{PD} \frac{dV_{PD}}{dt}$

Begin with the above equations and show that  $V_{PD}(t) = V_{DD} - \frac{I_{PD}}{C_{PD}}t$ .

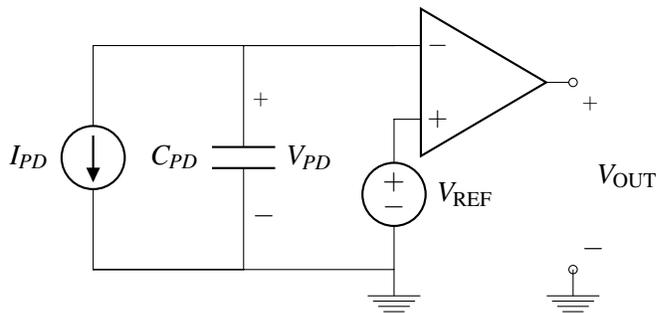
**Hint:** Follow passive sign convention.

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- (b) (6 points) When feeding information from circuits into computers, we need to convert from our continuous-valued analog signals into discrete-valued digital signals the computer can understand using an analog-to-digital converter (ADC).

One type of ADC uses the time it takes for an event to occur in its conversion (converting time to the digital domain involves counting at a steady rate until the event occurs). We care about the time it takes for the comparator output to change.



Parameter	Unit	Value
$I_{PD}$	A	$1 \cdot 10^{-3}$
$C_{PD}$	F	$1 \cdot 10^{-9}$
$V_{REF}$	V	0.5
$V_{DD}$	V	1.0

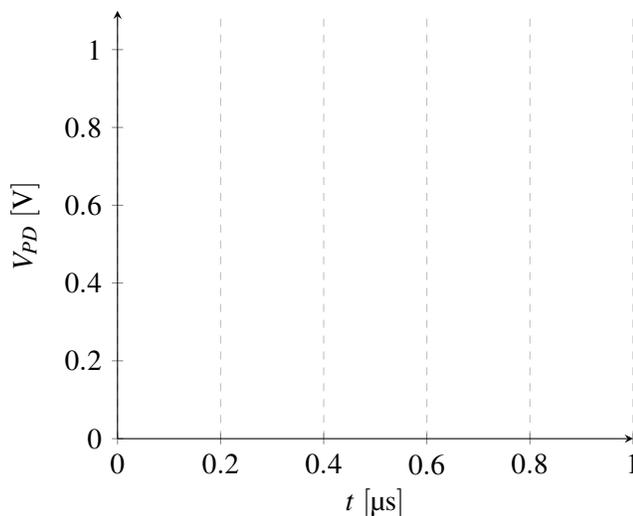
Figure 7.2: Integrating ADC

Table 7.1: Numerical values for parts (b) and (c)

Draw  $V_{PD}(t)$  in the graph below, where  $V_{PD}(t = 0) = V_{DD}$ . Clearly label the following with numerical values:

- Slope of the  $V_{PD}(t)$  vs.  $t$  curve, i.e.  $\frac{dV_{PD}}{dt}$ .
- $t_{\text{flip}}$  where  $V_{PD}(t_{\text{flip}}) = V_{REF}$  and the comparator output goes high for the first time
- $t_{\text{zero}}$  where  $V_{PD}(t_{\text{zero}}) = 0V$

**Hint:**  $1\mu\text{s} = 1 \cdot 10^{-6}\text{s}$ .



**Your answer to part (b)**

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- (c) (10 points) Everyone in your picture is holding still, and in previous parts we assumed a constant current across the capacitor. However, someone just turned on strobe lights! You only want a picture of people, so we can treat the flashing lights as interference. Now our full circuit looks like Figure 7.3

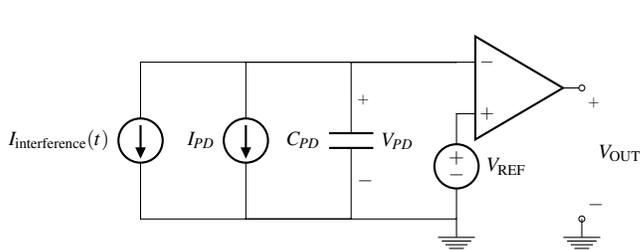


Figure 7.3: Model with interference

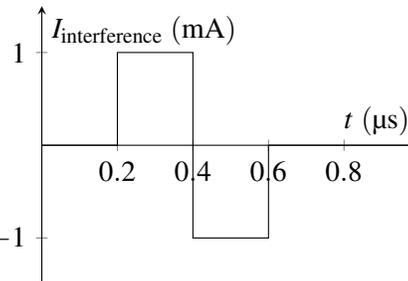


Figure 7.4: Interference current for part (c)

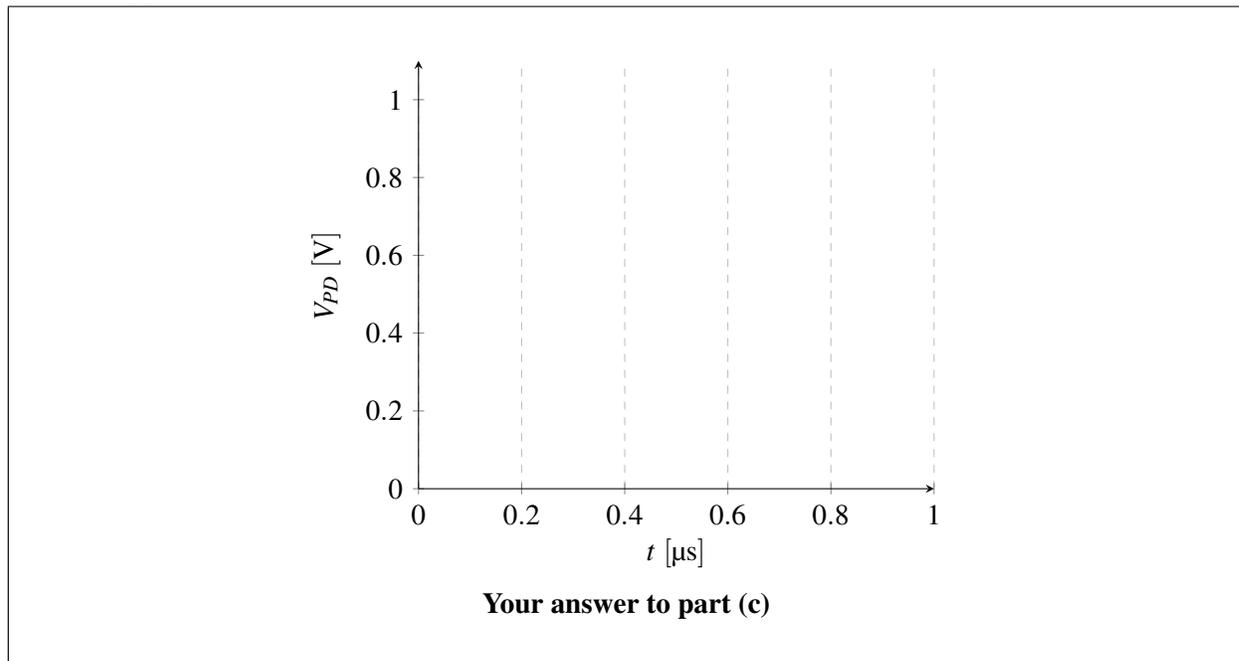
For this subpart, use the interference current defined in Figure 7.4 and the values in Table 7.1 (repeated for convenience).

Parameter	Unit	Value
$I_{PD}$	A	$1 \cdot 10^{-3}$
$C_{PD}$	F	$1 \cdot 10^{-9}$
$V_{REF}$	V	0.5
$V_{DD}$	V	1.0

Table 7.1 repeated for convenience

Draw  $V_{PD}(t)$  in the graph below given  $V_{PD}(0) = V_{DD}$ . Clearly label  $\frac{dV_{PD}}{dt}$  for every line segment in your graph with numerical values. Also find  $t_{flip}$  where  $V_{PD}(t_{flip}) = V_{REF}$ .

**Hint:**  $V_{PD}(t)$  is continuous.



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### 8. Otamatone Stars (28 points)

Your friendly lab TAs Alan and Ryan are trying to become YouTube musical sensations by playing the otamatone, which is a funny looking instrument shaped like a music note (Figure 8.1). With one hand you press your fingers to the touch pad on the stem of the otamatone, and with the other hand you squeeze open its mouth, which plays the sound corresponding to the position of your finger. As the position of your finger moves up the stem (away from the mouth) the frequency of the sound gets higher.

Instead of buying an otamatone, Ryan thinks it's cooler to build one. He has a spare "Black Box Speaker System" that takes a voltage signal input, and outputs a sound to a speaker, as shown in Figure 8.2.

All that he is missing is an input for the black box, but you notice that you can design the pad on the stem of the otamatone exactly like you designed the one-dimensional resistive touchscreen, as seen in Figure 8.3.

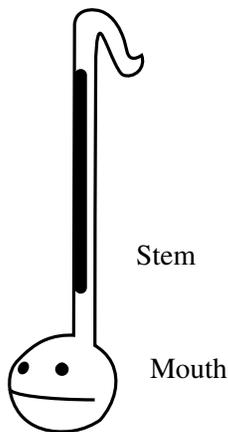


Figure 8.1: An Otamatone

You may find the following helpful:

- For Ryan's Black Box Speaker, the higher the voltage input,  $V_{BB}$ , the higher the frequency of the sound.
- The Black Box Speaker requires a minimum input voltage of  $V_{BB,min} > 0$  and outputs its lowest frequency at the input voltage,  $V_{BB} = V_{BB,min}$ . Frequency will be higher for  $V_{BB} > V_{BB,min}$ .
- The darkly shaded resistive bars in Figure 8.3 are identical with a cross sectional area  $A$ , uniform resistivity  $\rho$ , and length  $L$ .
- $x$  in Figure 8.3 indicates the position of touch.
- **We need to design an otamatone such that as we touch closer to the top ( $x = L$ ), output sound with higher frequency is produced.**

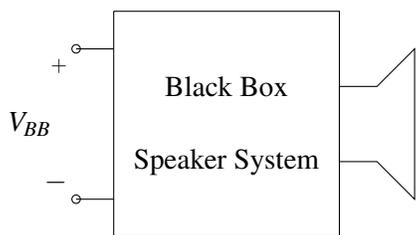


Figure 8.2: Black Box Speaker System

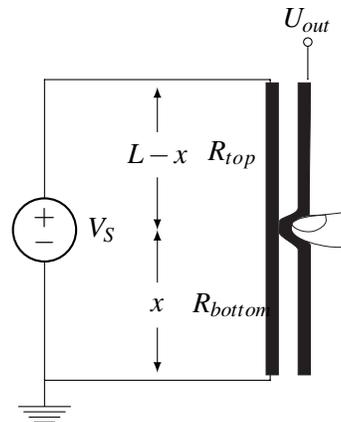


Figure 8.3: Resistive Touchscreen Schematic

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- (a) (3 points)  $R_{bottom}$  is the resistance of the **left resistive bar** below the finger touch point  $x$ ;  $R_{top}$  is the resistance of the left resistive bar above the touch point. Find  $R_{bottom}$  and  $R_{top}$  in terms of  $x$  and other physical parameters.

- (b) (3 points) Find  $U_{out}$  of the touch portion of this circuit in terms of  $V_S$ ,  $R_{top}$  and  $R_{bottom}$ . Show work or provide justification for your answer.

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- (c) (3 points) Can we directly plug our  $U_{out}$  into our black box speaker system if we want to utilize **the full range of our touchscreen**? Recall that the Black Box requires a minimum input voltage of  $V_{BB,min} > 0$  to function. Justify your answer.

- (d) (6 points) Your discussion TAs, Rishi and Sarika, see that you are working hard on your design. To help you out, they give you the following circuit below.

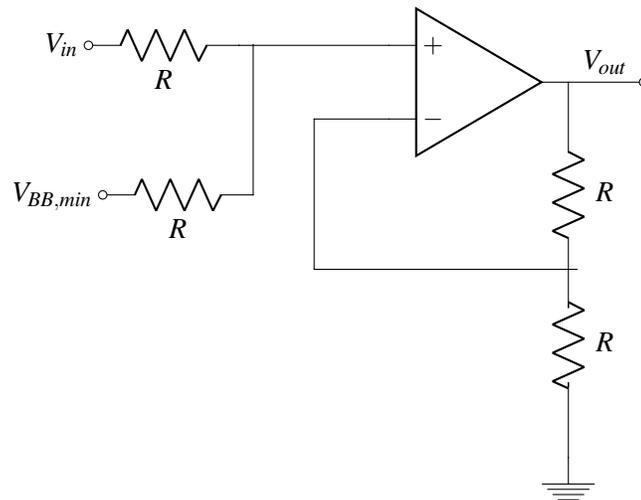


Figure 8.4: Circuit for part (d)

Find  $V_{out}$  in terms of  $V_{in}$ . What does the circuit do?

Show your work. Ignore the op-amp supply voltages for the calculations. Label any nodes you define.

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- (e) (6 points) Now, complete your otamatone design! Draw the connections between the components in the figure below so that the circuit blocks function as intended. Recall that you want to increase frequency of the speaker system as you move your finger toward the top of the otamatone stem. You may use **only one additional op-amp and one additional voltage source** if needed and no other components.

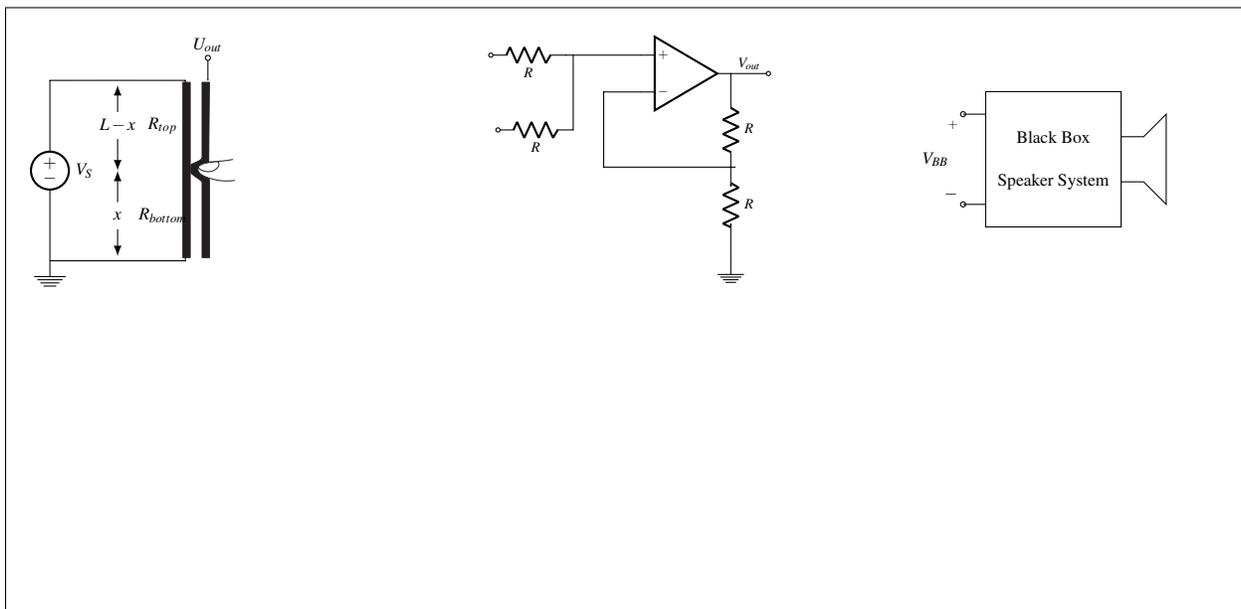


Figure 8.5: Your answer to part (e)

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- (f) (6 points) Using your design from Figure 8.5, find your  $V_{BB}$ , the signal going into the black box speaker system, as a function of  $x$ , the location of touch on the touch bar.

- (g) (1 point) Would you hit like, comment, and subscribe on Alan's YouTube channel? (*This is a fun question! Any answer will receive full credit.*)

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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 8 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 28 pages on the exam, so there should be 14 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 TWO handwritten 8.5" × 11" note sheets (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!**

Do not turn this page until the proctor tells you to do so.