EECS 16A Designing Information Devices and Systems I
Summer 2017 D. Aranki, F. Maksimovic, V. Swamy

Midterm 2

Exam Location: 531 Cory, DSP Exam

PRINT your student ID: ________________________________

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

PRINT your discussion section and GSI(s) (the one you attend): ________________________________

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 do you enjoy most about EE16A? (1 point)**

2. **Write down a pun or a joke about circuits. (0 points)**

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

3. Cover Your Basis (7 points)

Consider the set $S = \left\{ \begin{bmatrix} \alpha - \beta \\ \alpha + 2\beta \\ -2\alpha + \beta \end{bmatrix} \middle| \alpha, \beta \in \mathbb{R} \right\}$. You are told that S, alongside the traditional vector addition and scalar vector multiplication, constitutes a vector space.

(a) (2 points) **Find a basis** for the vector space S.

(b) (1 point) What is the **dimension** of the vector space S?

(c) (4 points) Consider a **new** vector space $S_{\text{new}} \subset \mathbb{R}^3$ with its basis being the columns of the matrix

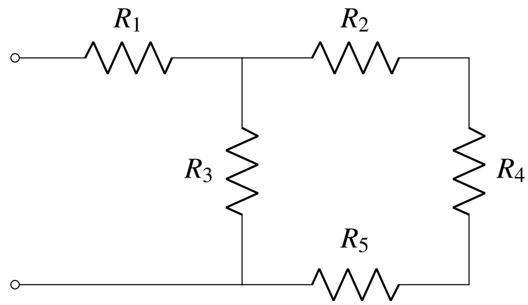
$$\mathbf{B} = \begin{bmatrix} -1 & 1 \\ -2 & 1 \\ 1 & -3 \end{bmatrix}.$$

Write the coordinates of the vector $\vec{x} = \begin{bmatrix} 5 \\ 9 \\ -7 \end{bmatrix}$ in the basis $\mathbf{B}$. That is, calculate $[\vec{x}]_{\mathbf{B}}$.

Hint: $[\vec{x}]_{\mathbf{B}}$ is a vector in $\mathbb{R}^2$.

4. Mechanical Circuits (15 points)

(a) (3 points) **Find the equivalent resistance** R_{eq} between the two terminals if $R_1 = 12.5\,\Omega$, $R_2 = 5\,\Omega$, $R_3 = 15\,\Omega$, $R_4 = 5\,\Omega$, and $R_5 = 5\,\Omega$.



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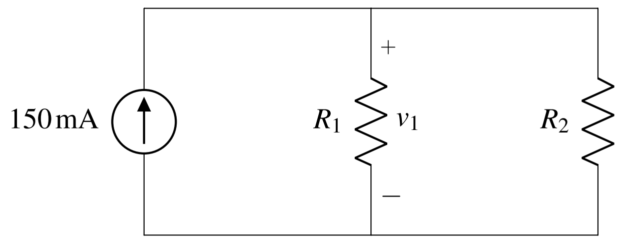
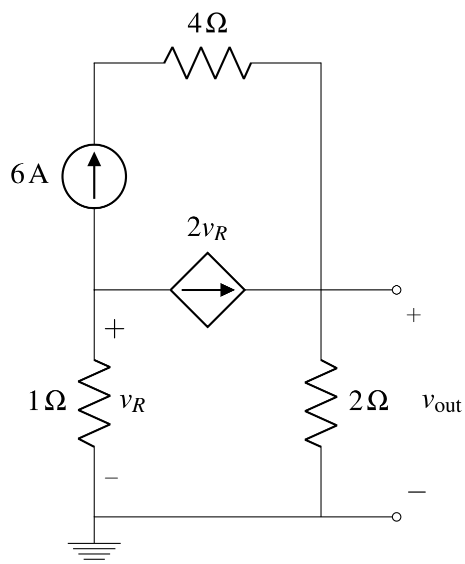
(b) (4 points) Consider the following circuit below:



i. **Find the voltage** v_1 across R_1 if $R_1 = 10\,\Omega$ and $R_2 = 20\,\Omega$.

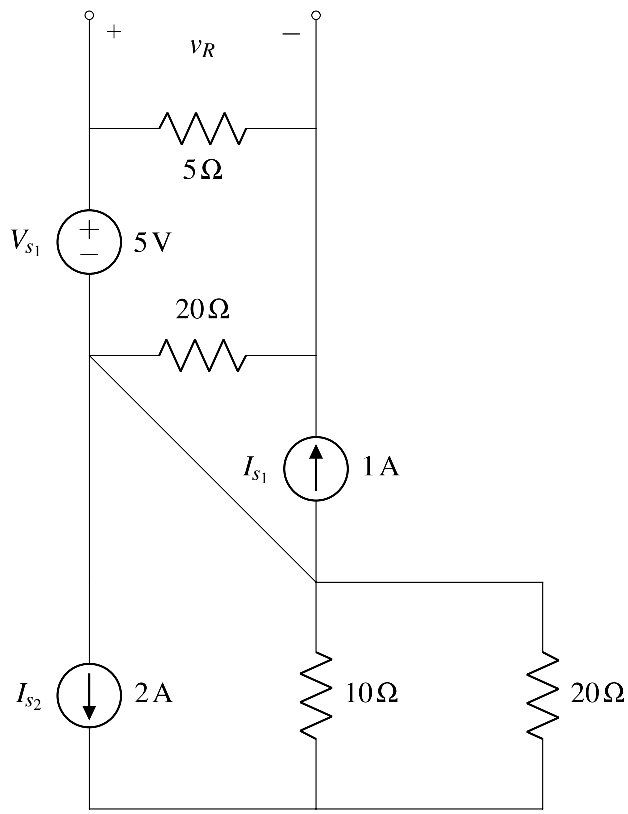
ii. **Calculate the power** P_1 dissipated by R_1 if $R_1 = 10\,\Omega$ and $R_2 = 20\,\Omega$.

(c) (8 points) Use nodal analysis to **find the voltage** v_{out} in the following circuit below.



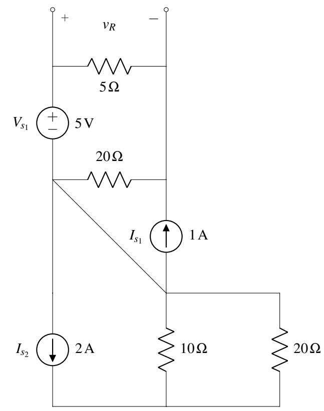
5. Taking the Super-L (12 points)

Consider the following circuit below:



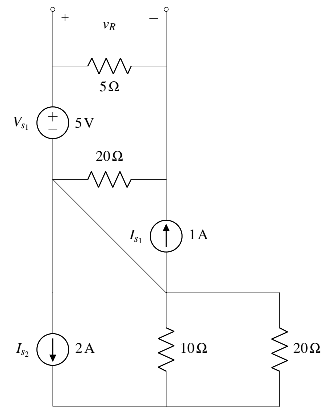
In this problem, you will use *superposition* to find the voltage v_R across the $5\,\Omega$ resistor.

(a) (3 points) First, turn off all sources *except* V_{s_1}. Find v_{R_1}, the voltage across the $5\,\Omega$ resistor, if all sources *except* V_{s_1} are turned off.

A copy of the circuit for reference: 

(b) (3 points) Now turn off all sources *except* I_{s_1}. Find v_{R_2}, the voltage across the $5\,\Omega$ resistor, if all sources *except* I_{s_1} are turned off.

A copy of the circuit for reference:

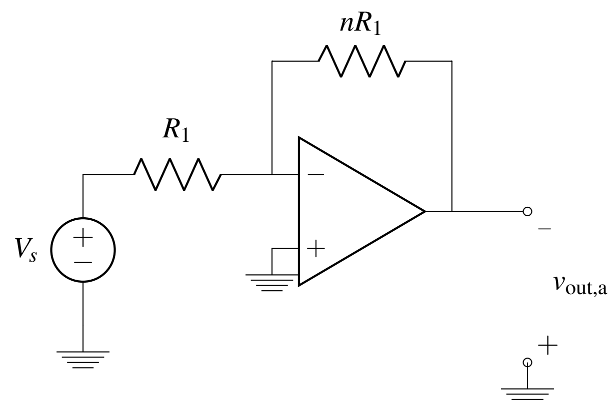


(c) (3 points) Now turn off all sources *except* I_{s_2}. Find v_{R_3}, the voltage across the $5\,\Omega$ resistor, if all sources *except* I_{s_2} are turned off.

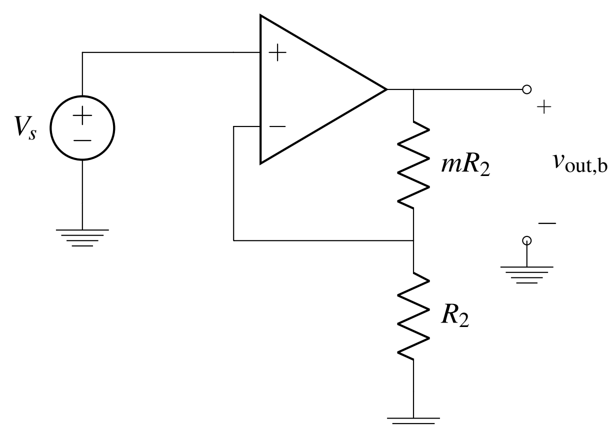
(d) (3 points) Now **find the voltage** v_R across the $5\,\Omega$ resistor if *all sources* are on.

6. Golden Rules Op-Amps (14 points + 4 BONUS points)

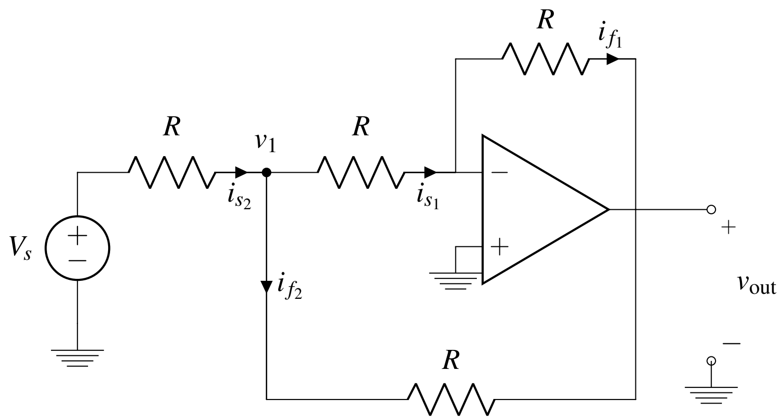
(a) (2 points) **Find the voltage** $v_{\text{out,a}}$ as a function of the voltage V_s and n. *Use the Golden Rules.*
Note: Pay careful attention to the polarity of the voltage $v_{\text{out,a}}$.



(b) (2 points) **Find the voltage** $v_{\text{out,b}}$ as a function of the voltage V_s and m. *Use the Golden Rules.*



(c) (10 points) **Find the currents** labeled i_{s_1}, i_{f_1}, i_{f_2}, and i_{s_2}, **and the voltage** v_{out}, as a function of the voltage at the node v_1 *only*, **NOT** the source voltage V_s. Assume that the resistance $R = 1\,\Omega$. Show your work in the subsections provided and fill in the table at the end with your results. *Use the Golden Rules*.



i. Find i_{s_1} as a function of v_1.

ii. Find i_{f_1} as a function of v_1.

iii. Find v_{out} as a function of v_1.

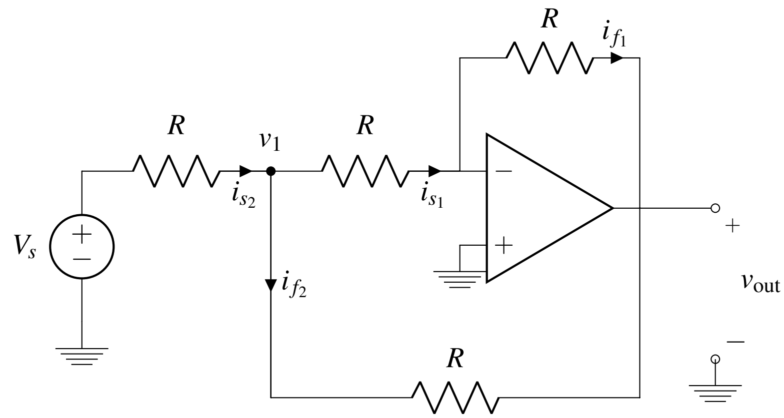
iv. Find i_{f_2} as a function of v_1.

v. Find i_{s_2} as a function of v_1.

i_{s_1}	i_{f_1}	v_{out}	i_{f_2}	i_{s_2}

(d) (4 **BONUS** points) In the circuit, find v_{out} as a function of V_s. Assume that the resistance $R = 1\,\Omega$. *Use the Golden Rules*.

Hint: This is the same circuit as in part (c). You may want to use your results from part (c).



7. Thévenin Rhymes with Almost Nothing (14 points)

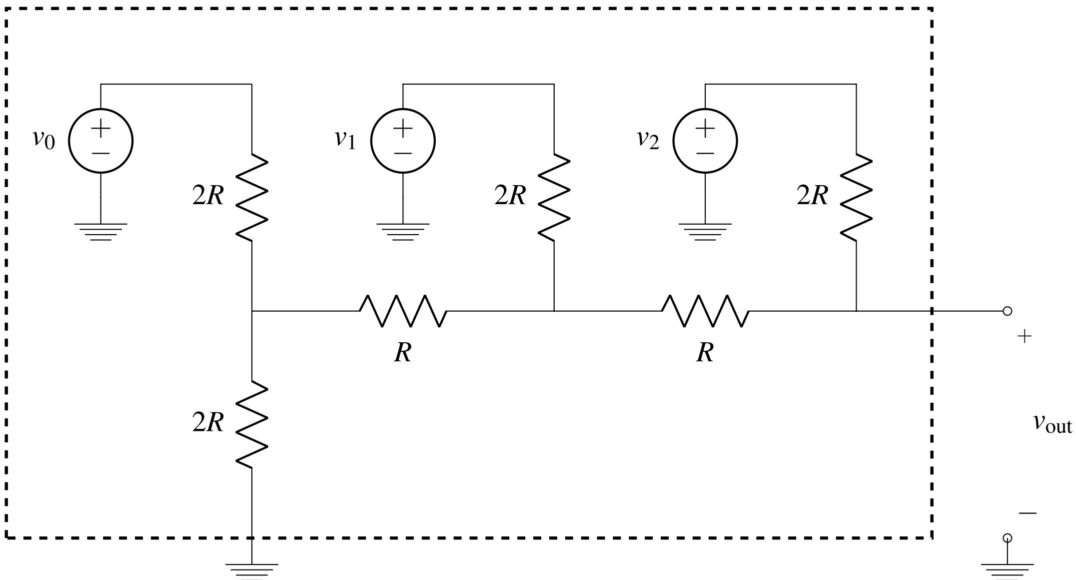
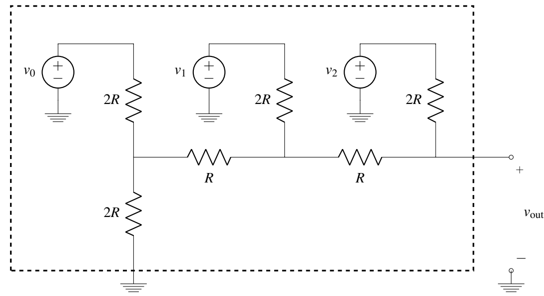


Figure 7.1: Three stage resistor ladder.

(a) (4 points) This circuit has three sources v_0, v_1, and v_2 connected to a resistor network. What is the **Thévenin equivalent resistance** R_{th} of this circuit at the terminals labeled v_{out}?

A copy of the circuit for reference: 

(b) (4 points) Find the **Thévenin equivalent voltage** ($V_{th} = v_{out}$) of this circuit at the terminals labeled v_{out}. You are given the following information:

i. The output voltage when v_0 is **on** and *all other sources* are off is $\frac{v_0}{8}$.

ii. The output voltage when v_1 is **on** and *all other sources* are off is $\frac{v_1}{4}$.

(c) (6 points) Now consider the case when we attach a resistor with resistance $3R$ to the output of our circuit. We set the voltage inputs so that $v_0 = 8V_{\text{DD}}$, $v_1 = 4V_{\text{DD}}$, and $v_2 = 2V_{\text{DD}}$. **Calculate the current** i_{out} **through the load resistor as a function of** V_{DD} **and** R.

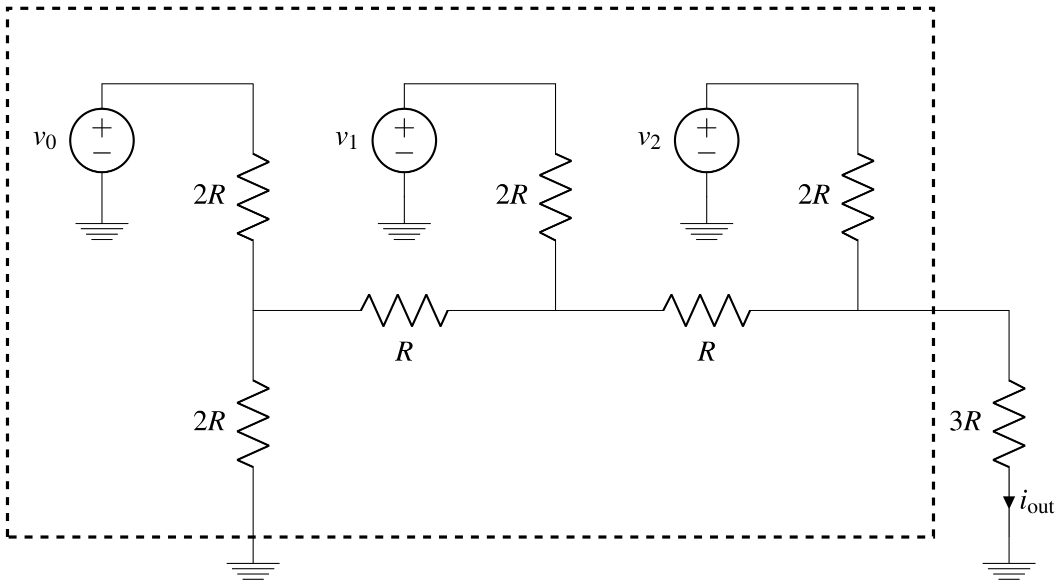


Figure 7.2: Loaded resistor ladder.

8. CompanEE-16A's Microcontroller (18 points)

A company in Berkeley called CompanEE-16A designs and manufactures microcontrollers for electrical engineers and hobbyists around the world. Their current microcontroller model, Version 1.6.A, is poorly documented. It's your job to find out how the microcontroller's pins behave when circuits are attached to them.

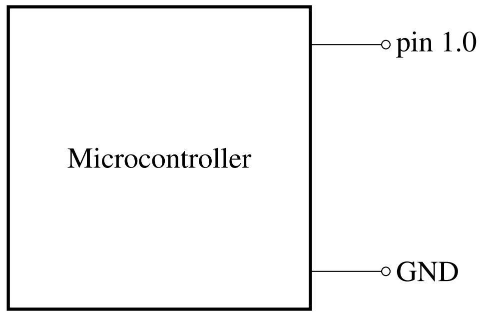


Figure 8.1: Microcontroller black box.

(a) (4 points) First off, you need to find an *equivalent circuit* for the microcontroller's output pins. You have access to a voltmeter (an open circuit that measures the voltage across its terminals) and an ammeter (a short circuit that measures the current through it). You also have a voltage source that displays the current that it is supplying.

i. Describe qualitatively how you would find the Thévenin equivalent voltage between pin 1.0 and GND.

ii. Describe qualitatively how you would find the Norton equivalent current between pin 1.0 and GND.

iii. Using these results V_{th} and I_{no}, and assuming that $V_{\text{th}} \neq 0$ and $I_{\text{no}} \neq 0$, write the expression that you would use to calculate the equivalent resistance between pin 1.0 and GND.

iv. Suppose that you measured $V_{\text{th}} = 0\,\text{V}$ and $I_{\text{no}} = 0\,\text{A}$, describe what you would need to do to find the equivalent resistance.

(b) (4 points) After taking the appropriate measurements using the methods in part (a), you find that $V_{\text{voltmeter}} = 4\,\text{V}$ and $I_{\text{ammeter}} = 2\,\text{mA}$. **Calculate** V_{th}, R_{th}, R_{no}, and I_{no}.

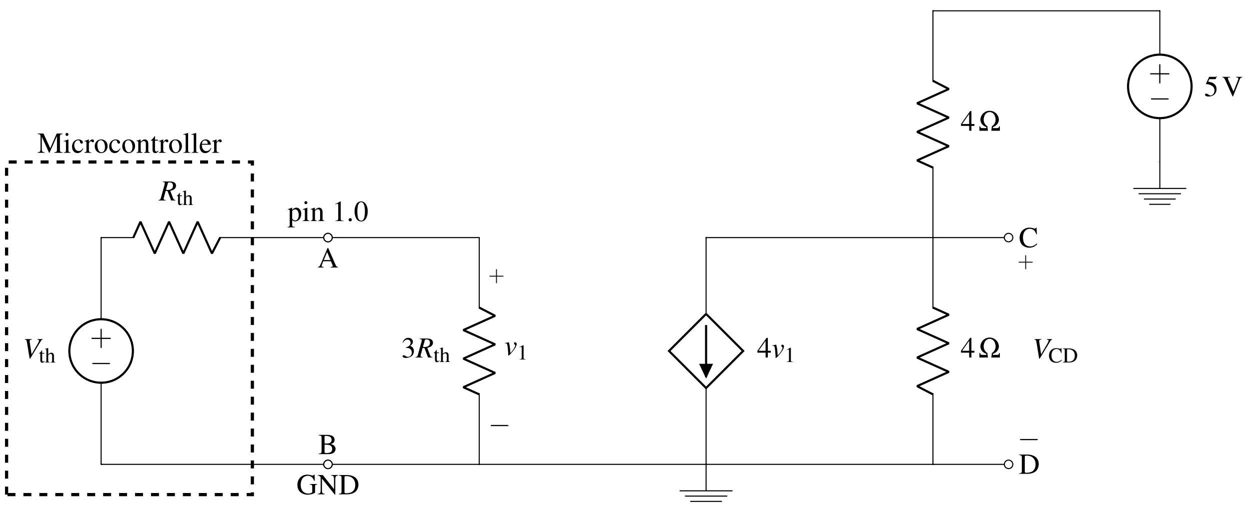
i. V_{th}

ii. I_{no}

iii. R_{th}

iv. R_{no}

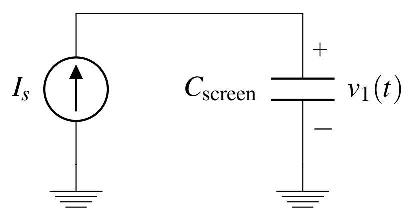
(c) (10 points) CompanEE-16A is so pleased with your work that they give you a Version 1.6.A microcontroller for free! Your friend saw your free microcontroller lying on your desk and thought that it was really interesting. He had been working on a mysterious circuit (shown below) for EE105 and wants to connect it onto your board. You connect terminal A of the mysterious circuit to pin 1.0 of the microcontroller and terminal B of the circuit to GND (shown below). **Find the voltage** V_{CD} between terminals C and D in terms of V_{th}.

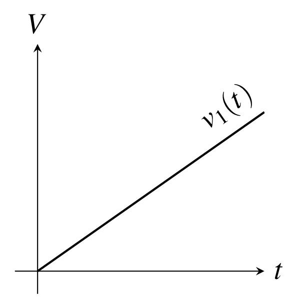


9. Touchy Currents (10 points)

In the capacitive touchscreen lab, you learned how a voltage source and a comparator can be used to determine whether a finger is touching a capacitive touchscreen. In this problem, you will explore how a current source can be used to detect touch.

(a) (4 points) The capacitor C_{screen} is connected to a current source with a constant value I_S as shown in the circuit below. The capacitor is initially uncharged. At time $t = 0$, the current source switches on. For time $t \geq 0$, the plot of the capacitor voltage $v_1(t)$ is a line. **Find the slope** of this line in terms of I_s and C_{screen}.





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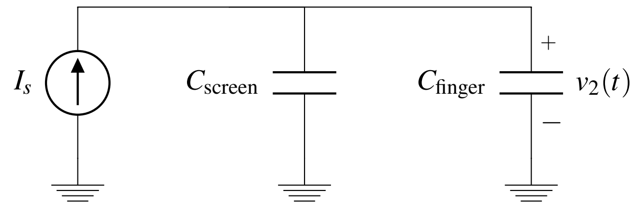
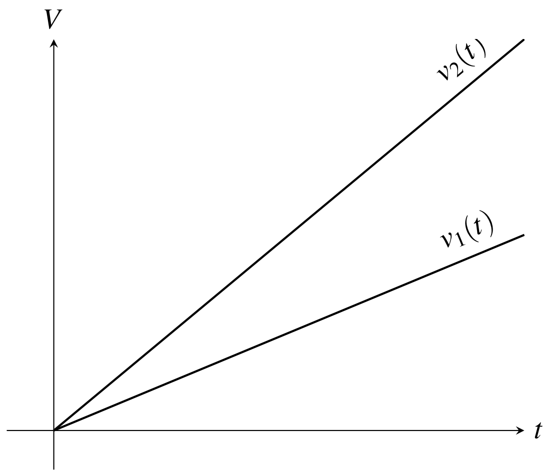
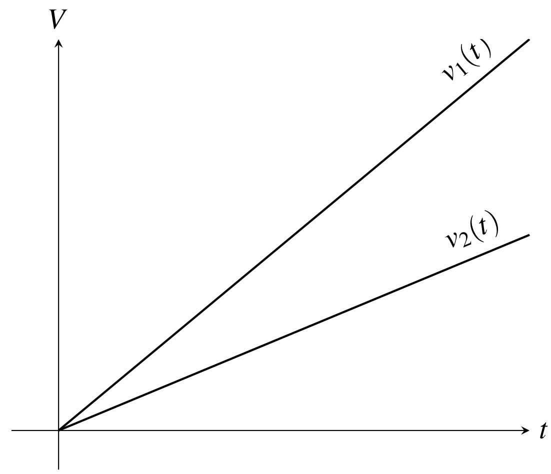
(b) (2 points) Suppose that instead, at time $t < 0$, a capacitor $C_{\text{finger}} > 0$ is placed in parallel with C_{screen} as shown in the circuit below. Both capacitors are initially uncharged. At time $t = 0\,\text{s}$, the current source switches on.



Circle the correct plot of $v_1(t)$ and $v_2(t)$, where $v_1(t)$ is the voltage over time when there is no touch and $v_2(t)$ is the voltage over time when there is touch. If the capacitive touch screen is being touched, it is being touched for the entire duration shown in the plot.

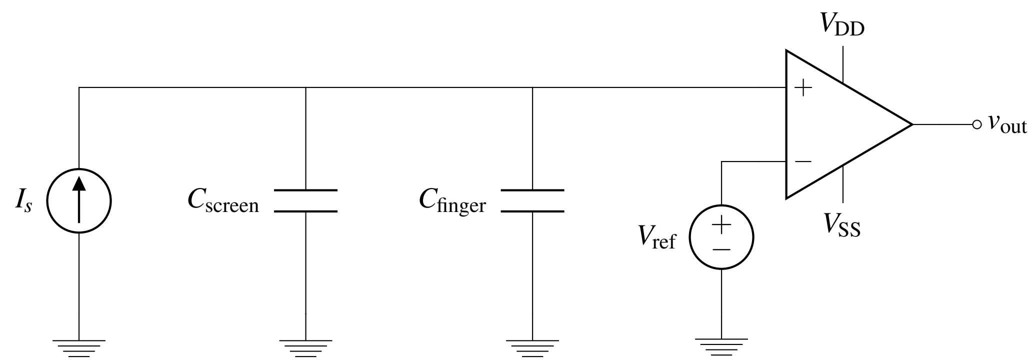


PLOT 1

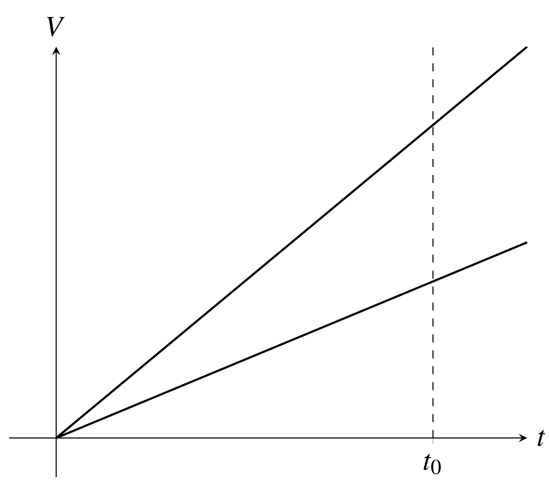


PLOT 2

(c) (4 points) You connect the circuit to a comparator, as shown here:



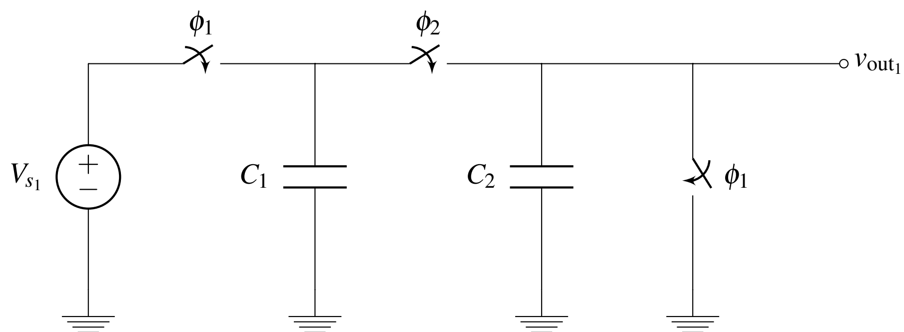
On the following set of axes, **label the lines** $v_1(t)$ and $v_2(t)$ corresponding to the plot you chose in part (b) and **draw a horizontal line** that represents an appropriate reference voltage V_{ref} that could be used to detect the presence of a touch at a time $t = t_0$.



10. Sorry, I don't make puns free of charge. (22 points)

Because of size constraints in modern semiconductor processes, circuit designers often use switches and capacitors instead of resistors to perform certain functions. We will investigate how charge sharing can be used to replace standard resistive circuits. In all parts of this question, assume that there is no leakage and that the capacitors reach steady state in each phase.

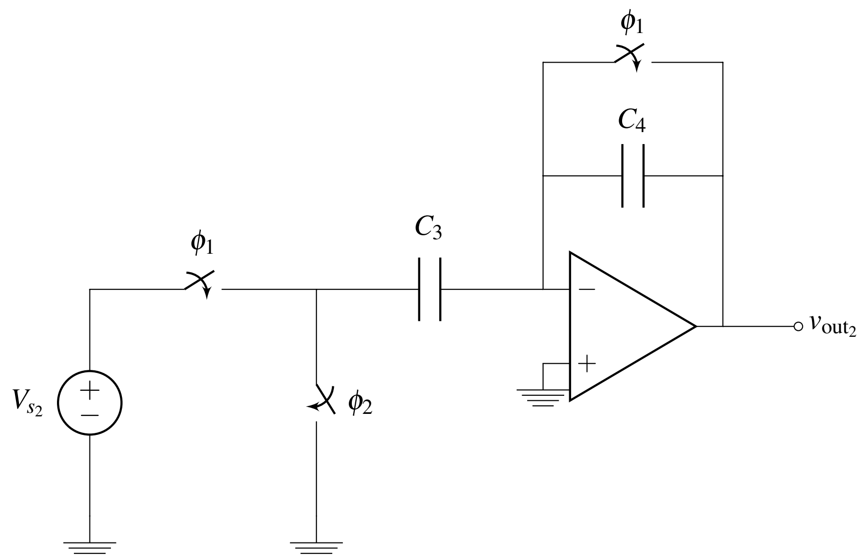
(a) (4 points) Consider the following two-phase circuit switched capacitor circuit:



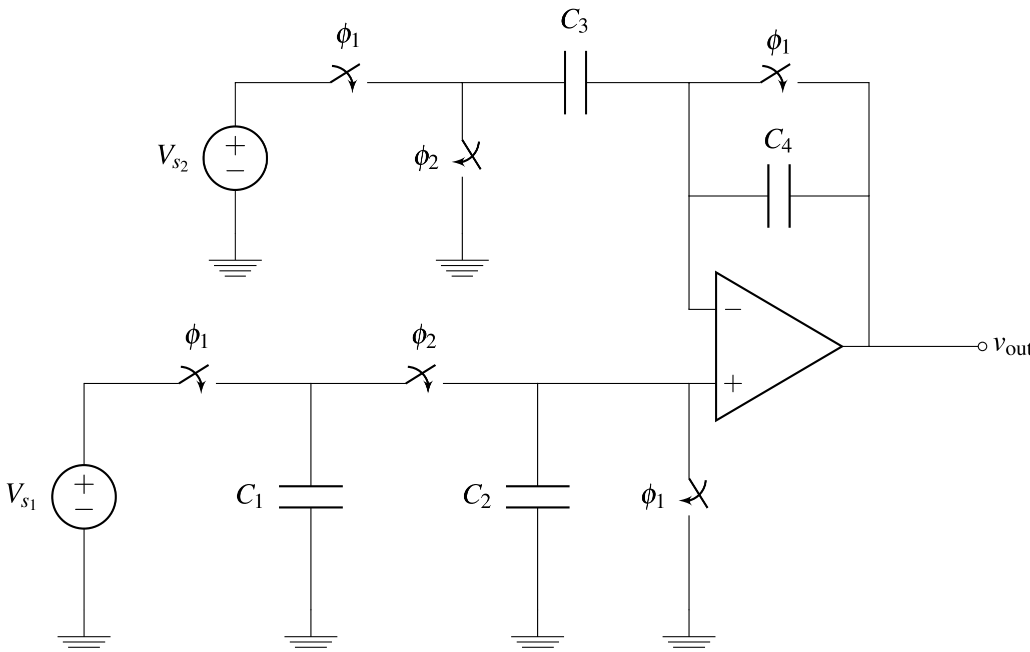
In phase ϕ_1, find the **voltage across** and the **charge on** *each capacitor* C_1 and C_2 in terms of the input source voltage V_{s_1} and the capacitances C_1 and C_2.

(b) (4 points) Now the switches change state, and we look at what happens in phase ϕ_2. Calculate the **voltage across** *both capacitors* C_1 and C_2 in terms of the input source voltage V_{s_1} and the capacitances C_1 and C_2.

(c) (4 points) In the following circuit, first, all switches labeled ϕ_1 are closed, and all switches labeled ϕ_2 are opened. Some time after the circuit reaches steady state, all switches labeled ϕ_2 are closed, and all switches labeled ϕ_1 are opened. **Find the voltage** v_{out_2} at steady state **only in the second phase** ϕ_2 as a function of the input source voltage V_{s_2} and the capacitances C_3 and C_4.



(d) (10 points) Now we combine both of the previous circuits into one. First, all switches labeled ϕ_1 are closed, and all switches labeled ϕ_2 are opened. Some time after the circuit reaches steady state, all switches labeled ϕ_2 are closed, and all switches labeled ϕ_1 are opened. **Find the voltage** v_{out} at steady state **only in the second phase** ϕ_2 as a function of the input source voltages V_{s_1} and V_{s_2} and the capacitances C_1, C_2, C_3, and C_4.



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EECS 16A Designing Information Devices and Systems I
Summer 2017 D. Aranki, F. Maksimovic, V. Swamy Midterm 2
Instructions

Read the following instructions before the exam.

You have 120 minutes for the exam. There are 10 problems of varying numbers of points. 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 113 points + 4 BONUS points possible on this exam. Partial credit will be given for substantial progress on each problem.

Distribution of the points:

Problem	1	2	3	4	5	6	7	8	9	10
Points	1	0	7	15	12	14 + 4 BONUS	14	18	10	22

The exam is printed double-sided. Do not forget the problems on the back sides of the pages!

There are 26 pages on the exam, so there should be 13 sheets of paper in the exam. 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.**

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

You may consult TWO handwritten 8.5” $\times$ 11” note sheets (front and back). No phones, calculators, tablets, computers, other electronic devices, or scratch paper are allowed. **No collaboration is allowed, and do not attempt to cheat in any way. Cheating will not be tolerated.**

Please write your answers legibly in the spaces provided on the exam; we will not grade outside a problem’s designed space unless you specifically tell us where to find your work. In general, show all of your work in order to receive full credit.

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!