MT2 Extra Practice

Exam location: Study Party in the Woz!

Note: These problems were unused from previous semesters, so we are releasing them for extra practice. The distribution of concepts is NOT indicative of the distribution of concepts on the actual midterm. These problems did *not* go through as extensive a filter before being released to students. In addition, there may be references to concepts that were not taught this semester. In particular, if you come across 'nodal analysis' it's just another name for 'Analyze a circuit to find all voltages/current flows using KCL/KVL/Ohm's Law.'

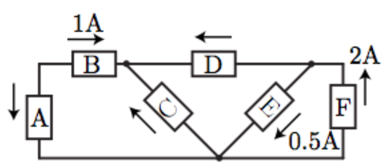
Section 1: Straightforward questions

Unless told otherwise, you must show work to get credit. There will be very little partial credit given in this section. Each problem is worth 8 points.

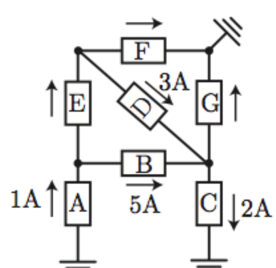
1. KVL/KCL Practice

Note: A box represents a resistor.

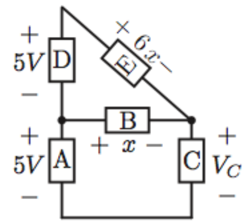
(a) Use KCL to find the values of i_a (the current through element A), i_c, and i_d for the circuit shown below. Use the arrows as the sign convention for currents. Which elements are connected in series?



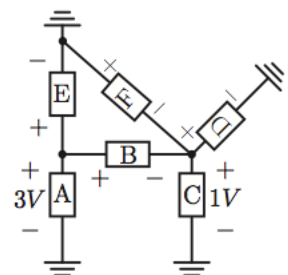
(b) Use KCL to find the values of i_e, i_f, and i_g for the circuit shown below. Which elements are connected in series?



(c) In the circuit below, x denotes some unknown real number. Use KVL to find the values of v_b (the voltage difference across element B), v_c, and v_e for the circuit shown below. Which elements are connected in shunt (i.e. parallel)?



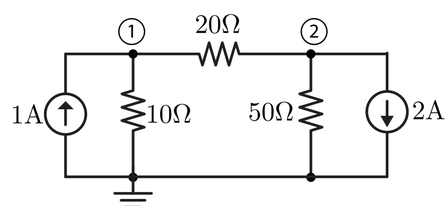
(d) Use KVL to find the values of v_b, v_d, v_e and v_f for the circuit shown below. Which elements are connected in shunt?



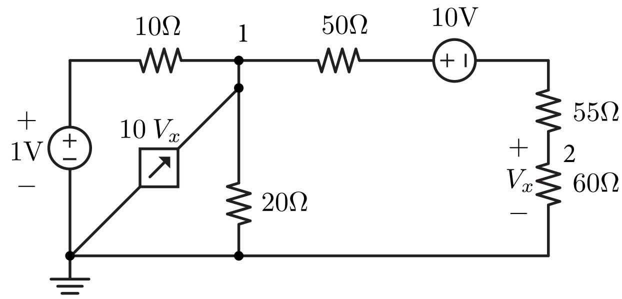
2. More KCL/KVL Analysis

Using techniques presented in class, label all unknown voltages (for every node/junction) and apply KCL to find them all (with respect to ground).

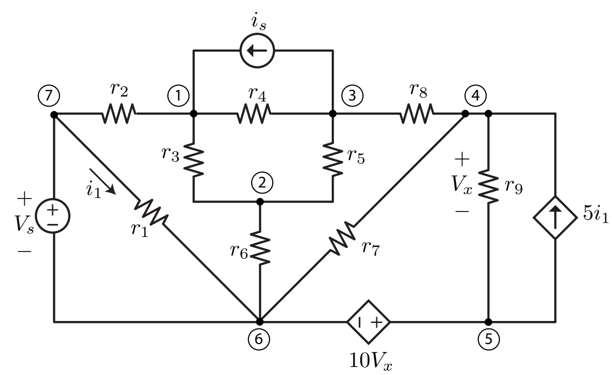
(a) Solve for all node voltages (with respect to ground) using KCL/KVL analysis. Verify with superposition.



(b) Solve for all node voltages (with respect to ground) using KCL/KVL analysis.

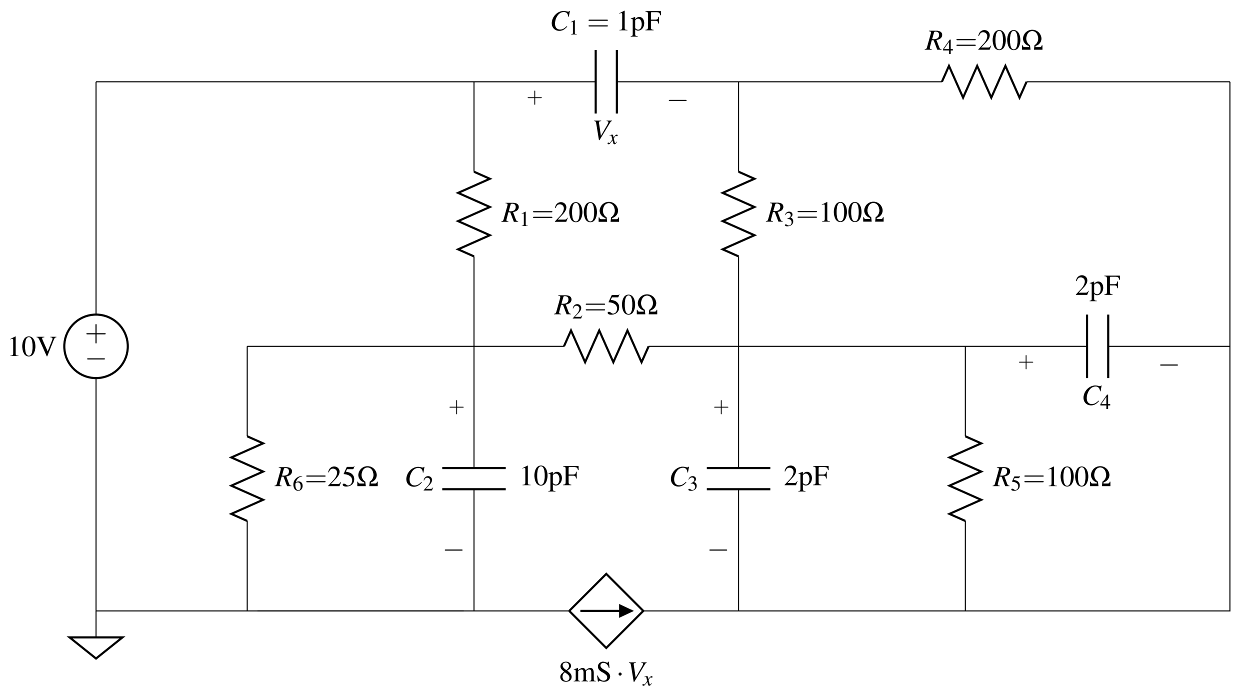


(c) Setup a matrix of equations in the form $Av = b_s$ using KCL/KVL analysis. The vector $v = (v_1\ v_2 \cdots)^T$ (use the node numbers given in the schematic).

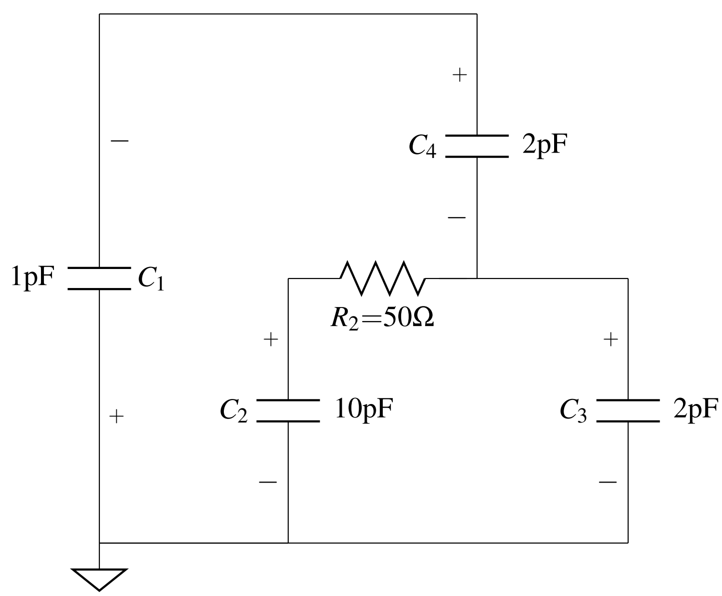


3. KCL/KVL Analysis + Capacitors

(a) Solve the following circuit in steady state using KCL/KVL analysis.

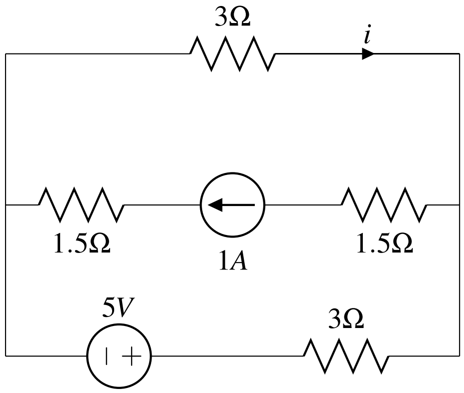


(b) After the circuit settles in steady-state from the previous part, disconnect the charged capacitors from the circuit and connect them in the configuration shown below. Polarity from part (a) is preserved. What are the voltages across, currents through and charge stored in each of the capacitors C_1, C_2, C_3 and C_4 in steady-state after the charge redistributes itself?

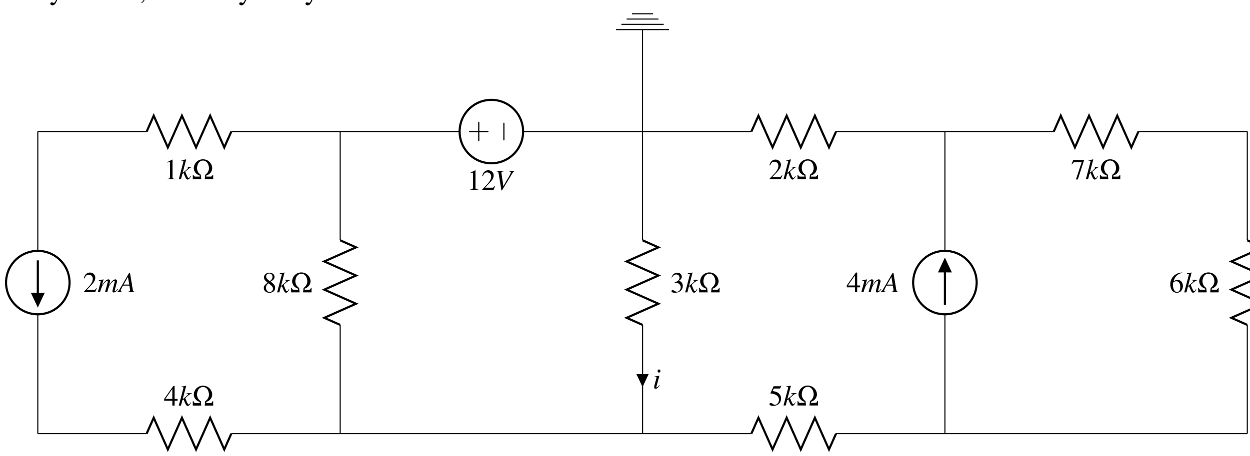


4. KCL/KVL Or Superposition?

(a) Solve for the current through the 3Ω resistor, marked as i, using superposition. Verify using nodal analysis. You can use IPython to solve the system of equations if you wish. Where did you place your ground, and why?

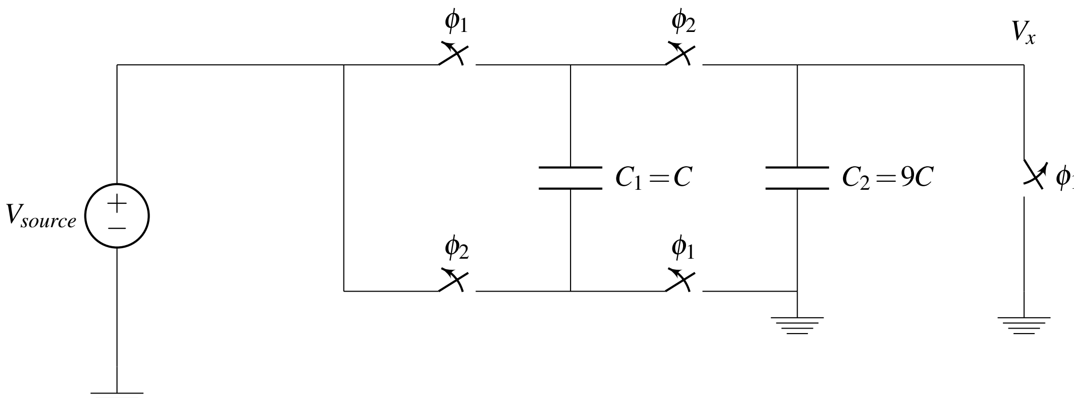


(b) Solve for the current through the $3k\Omega$ resistor, marked as i, using whatever method you want. This problem is more mechanically tedious than the rest, so we recommend using iPython. Which method did you use, and why did you chose it?



5. Capacitor Charge Sharing

Consider the following circuit:



In the first phase, all of the switches labeled ϕ_1 will be closed and all switches labeled ϕ_2 will be open. In the second phase, all switches labeled ϕ_1 open and all switches labeled ϕ_2 close.

(a) Draw polarity (+ and - signs) on the two capacitors C_1 and C_2. (It doesn't matter which terminal you label $+$ or $-$; just remember to keep these consistent through phases 1 and 2!)

(b) Draw the circuit in the first phase and in the second phase. Keep your polarity in part (a) in mind.

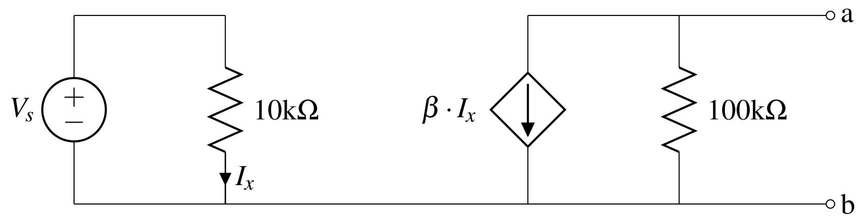
(c) Find the voltages and charges on C_1 and C_2 in the first phase. Be sure to keep the polarities of the voltages the same!

(d) Now, in the second phase, find the voltage V_x.

(e) (BONUS) If capacitor C_2 did not exist (i.e., had a capacitance of 0F), what would the voltage V_x be?

6. Equivalence

Find the Thévenin and Norton equivalents of the following circuit across the terminals a and b (in terms of V_s and β). Note that the current source is dependent on the current I_x.

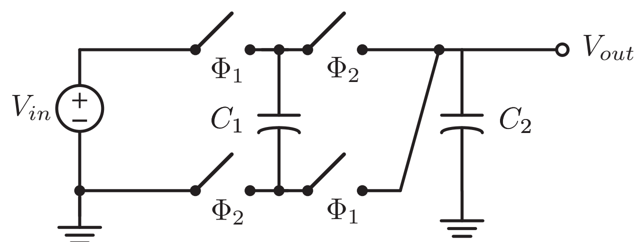


PRINT your name and student ID: ____________________

Section 2: Free-form Problems

7. DC-DC Voltage Divider

As we have learned in class, one of the reasons for using AC voltages is that we can easily transform the voltage (step up or step down) using transformers. Unfortunately, such circuits do not work at DC and we need to come up with other ways of dividing DC voltages. We have learned about resistive dividers, but we found issues such as inefficiencies. An alternative circuit, a capacitive charge pump, is shown below. It relies on two switches which are activated in sequence, first switch Φ_1 is closed (during this period Φ_2 switches are open), and next Φ_2 closes and Φ_1 is opened. In practice this is done periodically but for this problem we will analyze each phase separately. Note that V_{in} is a DC voltage.

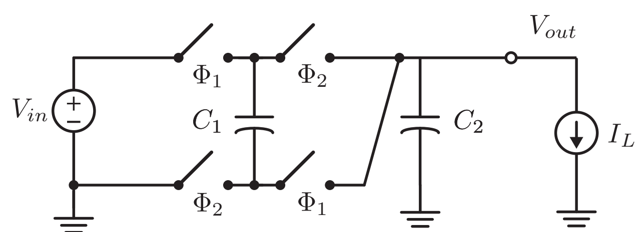


(a) During phase Φ_1, calculate the voltage across and charge stored by each capacitor C_1 and C_2.

(b) During phase Φ_2, calculate the output voltage V_{out} and show that it is a fraction of the input voltage V_{in}.

(c) For the special case of $C_1 = C_2$, calculate the output voltage and the efficiency of the system. To calculate the efficiency, calculate the energy stored in the capacitors during the end of phase Φ_1 and Φ_2.

(d) Assume that this circuit is used with a load represented by the current source $I_L = 10\text{mA}$. Suppose that the cycle described above repeats periodically at a rate of 10 kHz, or 10,000 times per second, with each phase Φ_1 and Φ_2 exactly 50% of each cycle. During phase Φ_2, which lasts 50μs, we wish the output voltage to not droop by more than 5mV. Specify the size of C_1 and C_2 to satisfy this constraint.

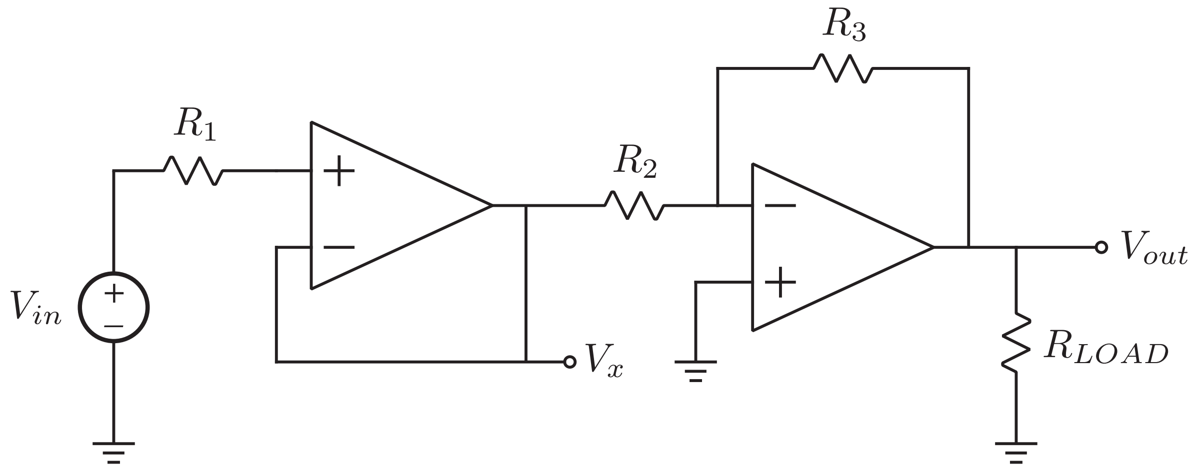


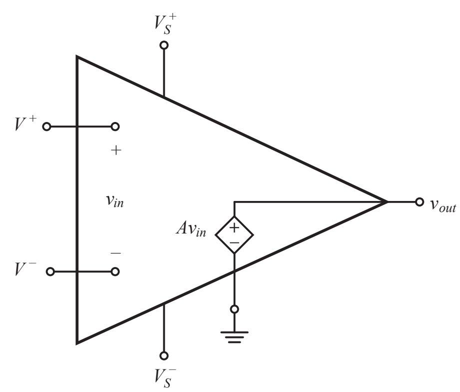
8. Thevenin's Theorem And Op-Amp Circuits!

You're given the below circuit – which cascades two opamps.

We're going to explore what this circuit does in several different ways.

(a) Let's first assume that the Golden Rules hold ($A = \infty$ for both the opamps) Calculate V_x in terms of V_{in}. Calculate V_{out} in terms of V_x, and therefore in terms of V_{in}.





(b) Now, suppose we remove the infinite gain assumption. The model of the op amp remains the same, but now A is finite for both opamps. This complicates our analysis...Thevenin and Norton, save us!

What is the Thevenin equivalent circuit at V_x with respect to ground *looking back*? (Imagine that you disconnect the rest of the circuit to the right of node x. Look at the rest of the circuit, and find the Thevenin voltage and equivalent resistance.)

(c) Redraw the circuit using the Thevenin equivalent you have obtained. Does it look simpler?

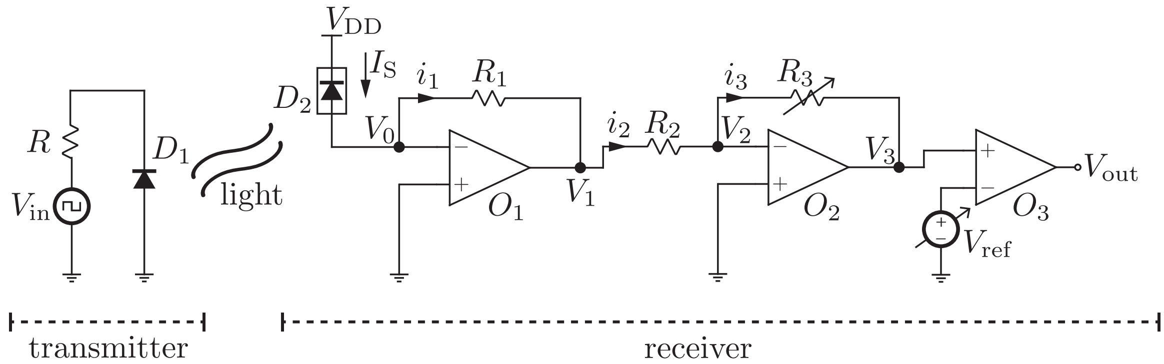
(d) Now, calculate the Thevenin equivalent circuit at V_{out} with respect to ground *looking back*. (Under the same finite-gain assumption as the previous part).

(e) Now, calculate V_{out} in the limit as $A \to \infty$. Do you get the same answer as before?

9. Wireless communication with an LED

Note: This problem is slightly more difficult (out of scope in difficulty) than a midterm problem. It was a HW problem from Fall 2015.

In this question, we are going to analyze the system shown in the figure below. It shows a circuit that can be used as a wireless communication system using visible light (or infrared, very similar to remote controls).



The element D_1 in the transmitter is a light-emitting diode (LED in short). An LED is an element that emits light where the brightness of the light is controlled by the current flowing through it. You can recall controlling the light emitted by an LED using your MSP430 in touch screen lab part 1. In our circuit, the current across the LED, hence its brightness, can be controlled by choosing the applied voltage V_{in} and the value of the resistor R. In the receiver, the element labeled as D_2 is a reverse biased solar cell. You can recall using a reverse biased solar cell in imaging labs 1 to 3 as a light controlled current source, by I_S we denote the current supplied by the solar cell. In this circuit the LED D_1 is used as a means for transmitting information with light, and the reverse biased solar cell D_2 is used as a receiver of light to see if anything was transmitted.

Remark: In imaging lab part 3, we have talked about how non-idealities such as background light affect the performance of a system that does light measurements. In this question we assume ideal conditions, that is, there is no source of light around except for the LED.

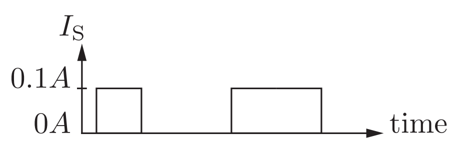
In our system, we define two states for the transmitter, the *transmitter is sending something* when they turn on the LED, and *transmitter is not sending anything* when they turn off the LED. On the receiver side, the goal is to convert the current I_S generated by the solar cell into a voltage and amplify it so that we can read the output voltage V_{out} to see if the transmitter was sending something or not. The circuit implements this operation through a series of op-amps. It might look look complicated at first glance, but we can analyze it a section at a time.

(a) Currents i_1, i_2 and i_3 are labeled on the diagram. Assuming the Golden Rules hold, is $I_S = i_1$? $i_1 = i_2$? $i_2 = i_3$? Treat the solar cell as an ideal current source.

(b) Use the Golden Rules to find V_0, V_1, V_2 and V_3 in terms of I_S, R_1, R_2 and R_3.
Hint: Solve for them from left to right, and remember to use the op-amp golden rules.

(c) In the previous part, how could you check your work to gain confidence that you got the right answer?

(d) Now, assume that the transmitter has chosen the values of V_{in} and R to control the intensity of light emitted by LED such that when *transmitter is sending something* I_S is equal to 0.1 A, and when the *transmitter is not sending anything* I_S is equal to 0 A. The following figure shows a visual example of how this current I_S might look like as time changes (note that this is just here for helping visualizing the form of the current supplied by the solar cell).



For the receiver, suppose $V_{\text{ref}} = 2V$, $R_1 = 10\,\Omega$, $R_2 = 1000\,\Omega$, and the supply voltages of the op-amps are $V_{\text{DD}} = 5V$ and $V_{\text{SS}} = -5V$. Pick a value of R_3 such that V_{out} is V_{DD} when the *transmitter is sending something* and V_{SS} when the *transmitter is not sending anything*?

(e) In the previous part, how could you check your work to gain confidence that you got the right answer?

10. Wine Barrel Filler

You own a wine tasting place in Berkeley! You have a very elegant dispenser set up for each kind of wine. To minimize the number of bottles you use, you dispense the wine directly from refillable rectangular barrels. To make sure that the barrels never run out, you want to design a level "detector" which will send the appropiate signal to the tank of wine to pour wine into a barrel until a certain level. Two lateral faces of the barrel (opposite to each other) are coated inside with a perfectly conducting material and you have wires coming out of the barrel at the two faces. You are given that the resistivity of wine is ρ. The dimensions of the barrels (other than height) are l and w. Design a circuit to control the level of the wine. You don't want it to go below a threshold h_{min} and above a threshold h_{max}. The only commands the circuit needs to output are "Fill" and "Stop Fill". Recall the formula $R = \frac{\rho l}{A}$.