This homework is due November 9, 2015, at Noon.

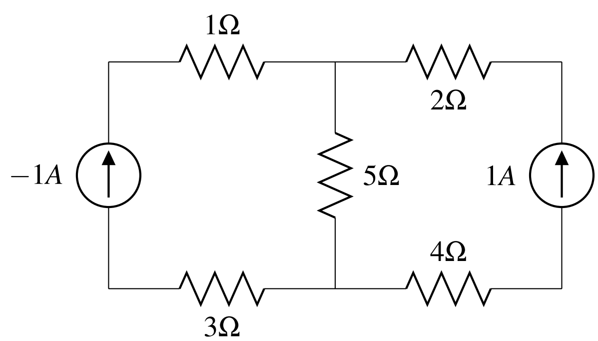
1. **Homework process and study group**

   Who else did you work with on this homework? List names and student ID's. (In case of hw party, you can also just describe the group.) How did you work on this homework?

2. **Review Problems**

   (a) How much power is dissipated in each of the resistors? How much power is supplied/dissipated by each of the current sources?

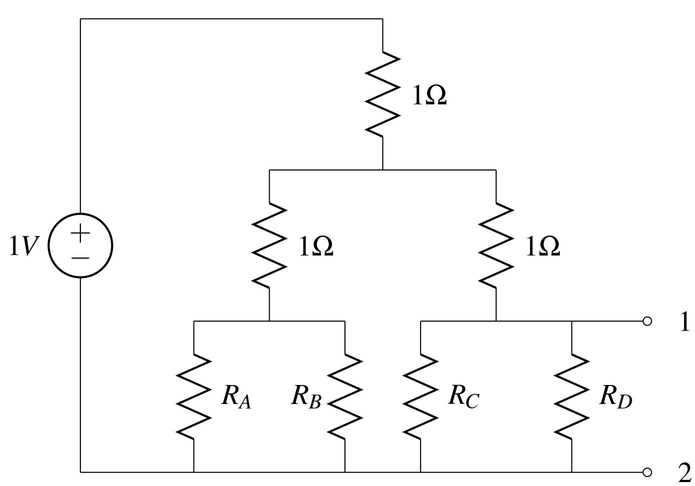
   `#power #ohmslaw`



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

   (c) Find the currents through R_A, R_B, R_C, and R_D in the diagram below and the voltage drop from 1 to 2. $R_A = R_B = R_C = R_D = 1\Omega$

   `#voltagedivider #ohmslaw`



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

(e) Construct the Norton and Thevenin equivalent circuit as seen from terminals 1 and 2 in the circuit above.

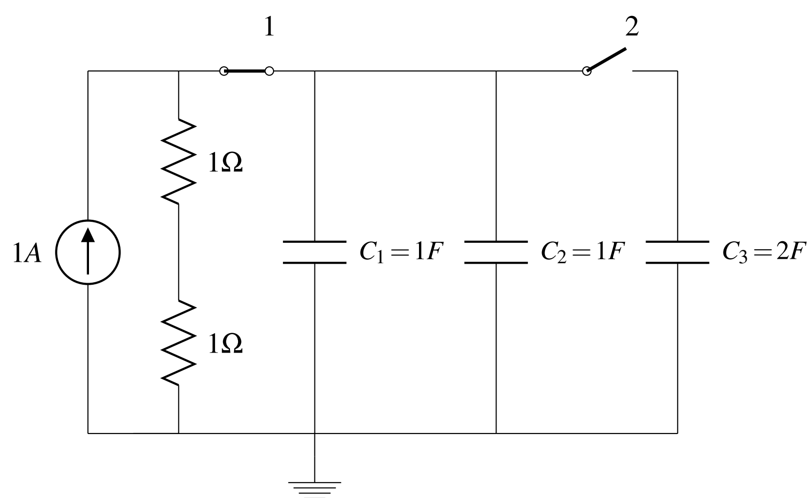
`#norton #thevenin`

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

(g) The circuit below is charged to steady steady state with the switch 1 closed and switch 2 open. Then switch 1 is opened and switch 2 closed. What is the final charge on and the voltage drop across capacitors C_1, C_2, and C_3 after the circuit reaches steady state again?

`#ohmslaw #chargesharing`

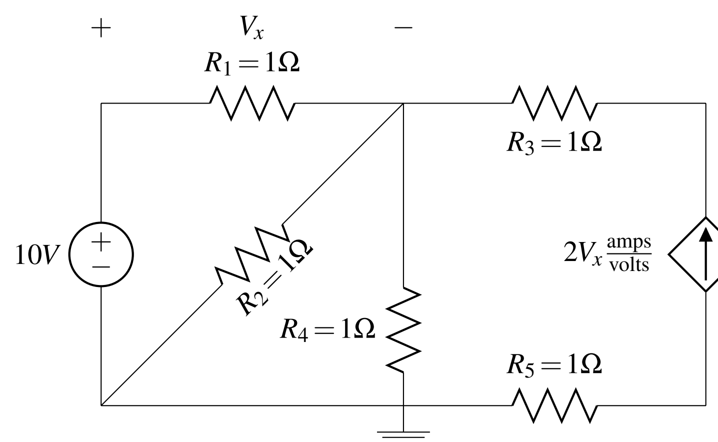
Initial Configuration



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

(i) Find the power dissipated in each resistor, R_1, R_2, R_3, R_4, R_5.

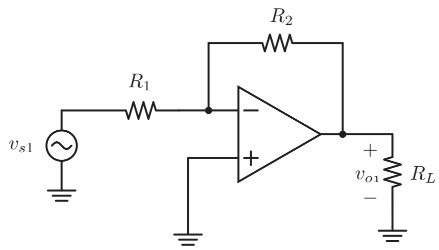
`#nodalanalysis #KCL #dependentsources #ohmslaw #power`

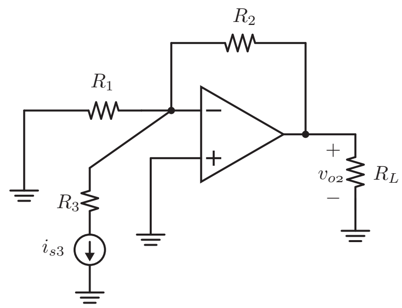


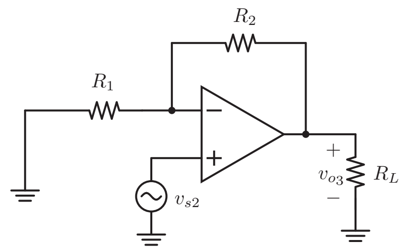
(j) In the previous part, how could you check your work to gain confidence that you got the right answer?

3. Amplifier with Multiple Inputs

#goldenrules #superposition







(a) Use the Golden Rules to find v_{o1} for the first circuit above.

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

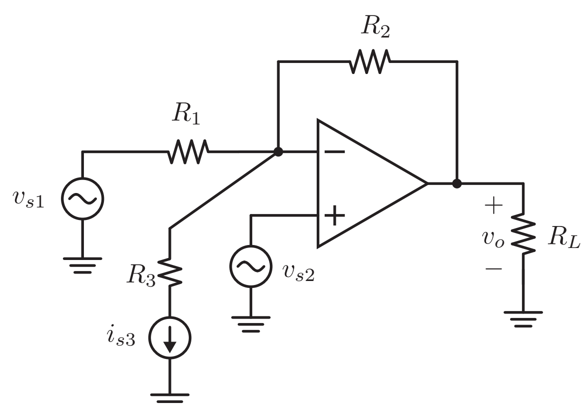
(c) Use the Golden Rules to find v_{o2} for the second circuit above.

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

(e) Use the Golden Rules to find v_{o3} for the third circuit above.

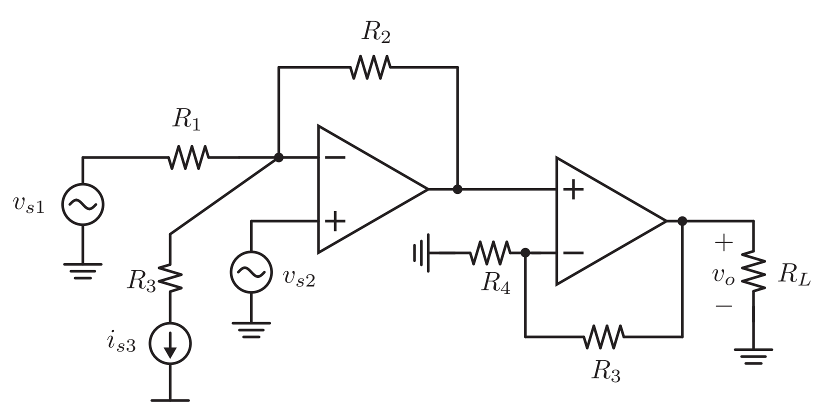
(f) In the previous part, how could you check your work to gain confidence that you got the right answer?

(g) Use the Golden Rules to find the output voltage v_o.



(h) Use superposition and the answers to the first few parts of this problem to check your work.

(i) Now add a second stage as shown below. Do the voltages from the first part change after adding the second stage? Do the voltages depend on R_L?
#loading #hw9q3



(j) Suppose $v_{s1} = 1\text{V}$, $v_{s2} = 1\text{V}$, $i_{s3} = 1\text{mA}$, and $R_1 = R_3 = 1\text{k}\Omega$ and $R_2 = R_4 = 0.5\text{k}\Omega$. For the three circuits in the first few parts of this problem, what is the power dissipated or generated by each independent source?

In the combined circuit in the previous section, what is the power dissipated or generated by each independent source?

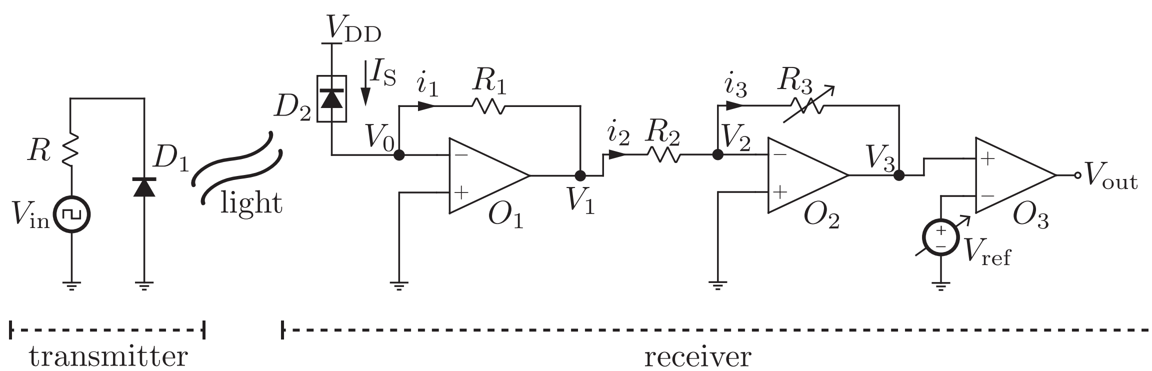
Comment on what this means about power vis-a-vis superposition.

`#linear #nonlinear`

4. Wireless communication with an LED

`#goldenRules`, `#amplifiers`, `#imagingLab`, `#touchscreenLab`

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.

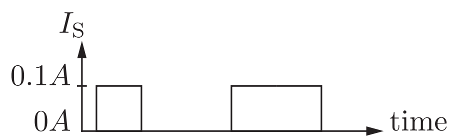
In our system, we define two states for the transmitter, the *transmitter is sending something* when they turn on the LED, and *transmitter is not sending anything* when they turn off the LED. On the receiver side, the goal is to convert the current I_S generated by the solar cell into a voltage and 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).

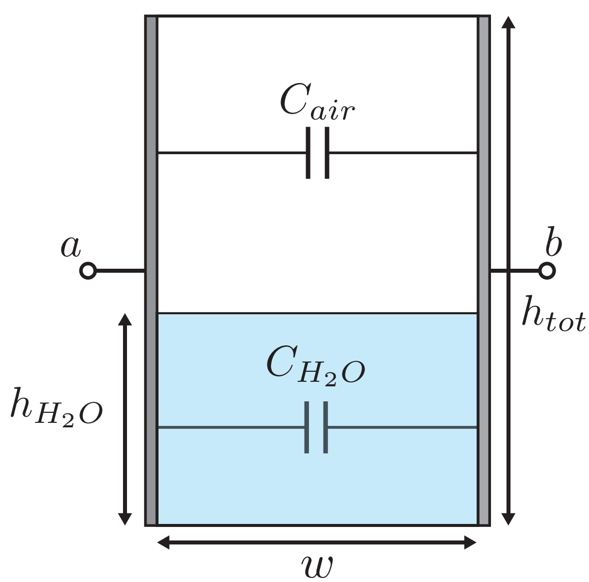


For the receiver, suppose $V_{ref} = 2V$, $R_1 = 10\,\Omega$, $R_2 = 1000\,\Omega$, and the supply voltages of the op-amps are $V_{DD} = 5V$ and $V_{SS} = -5V$. Pick a value of R_3 such that V_{out} is V_{DD} when the *transmitter is sending something* and V_{SS} when the *transmitter is not sending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

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

5. It's finally raining!

A lettuce farmer in the Salinas valley has grown tired of weather.com's imprecise rain measurements. So, she decided to take matters into her own hands by building a rain sensor. She placed a rectangular tank outside and attached two metal plates to two opposite sides in an effort to make a capacitor whose capacitance varies with the amount of water inside.



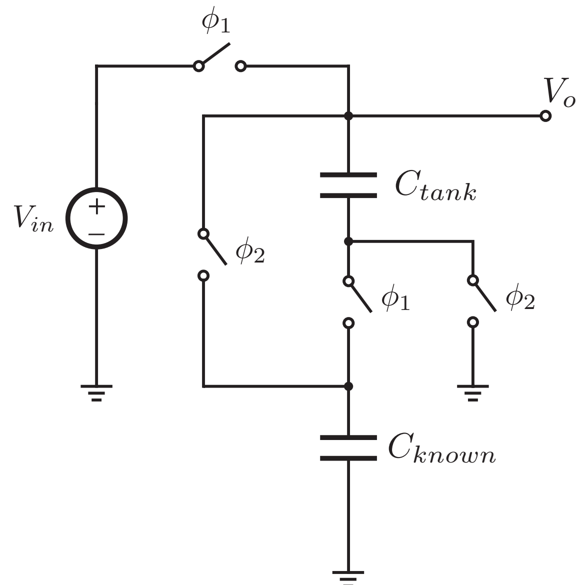
The width and length of the tank are both w (i.e. the base is square) and the height of the tank is h_{tot}.

(a) What is the capacitance between terminals a and b when the tank is full? What about when it is empty?
Note: the permittivity of air is ε, and the permittivity of rainwater is 81ε.
`#physicalcapacitance`

(b) Suppose the height of the water in the tank is h_{H_2O}. Modeling the tank as a pair of capacitors in parallel, find the total capacitance between the two plates. Call this capacitance C_{tank}

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

(d) After building this capacitor, the farmer consults the Internet to assist her with a capacitance measuring circuit. An random Anon recommends the following:



In this circuit, C_{tank} is the total tank capacitance that you calculated earlier. C_{known} is some fixed and known capacitor. Find the voltage V_o in phase ϕ_2 as a function of the height of the water. Note that in phase ϕ_1 all switches labeled ϕ_1 are closed and all switches labeled ϕ_2 are open. In phase ϕ_2, all switches labeled ϕ_1 are open and all switches labeled ϕ_2 are closed.

`#chargesharing`

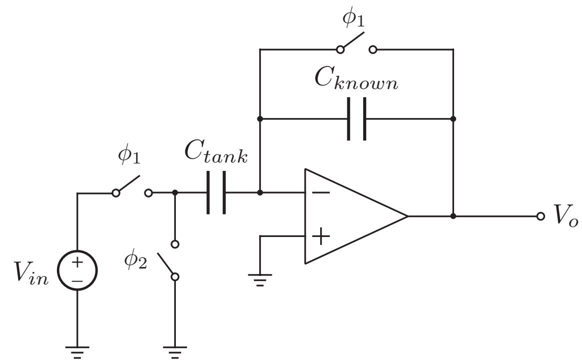
(e) Use IPython (or any other tool or just do it by hand) to plot this voltage V_o as a function of the height of the water. Vary the tank from empty to full. Use values of $V_{in} = 12$V, $w = 0.5$m, $h_{tot} = 1$m, and $\varepsilon = 8.854 \times 10^{-12}$F/m. This ε is called the *permittivity of free space*. For C_{known} use a similar tank that is known to always be empty.

(f) With the previous part, we were able to derive an expression for V_o. What does V_o represent? It's something we can measure! Our original goal was to determine what the height of the water in the tank without having to look inside it. Rewrite the last part to solve for h_{water}.

(g) How about we perform a sanity check on our answer. What are the units of your result for V_o and for h_{water}?

`#insanityprevention #dimensionalanalysis`

(h) **(BONUS Out-of-scope)** The farmer has become tired of solving the equation and wishes to generate a voltage proportional to the tank capacitance. A brief consultation with her daughter, who is taking Berkeley's EE105, yields the following circuit:



Calculate V_o as a function of h_{H_2O} in phase ϕ_2. Use the Golden Rules. *(Hint: think about what must happen to the charge on the capacitor C_{tank} in phase ϕ_2. Where does that charge have to go?)*
`#goldenrules #chargesharing #elegant`

6. **Your Own Problem** Write your own problem related to this week's material and solve it. You may still work in groups to brainstorm problems, but each student should submit a unique problem. What is the problem? How to formulate it? How to solve it? What is the solution?