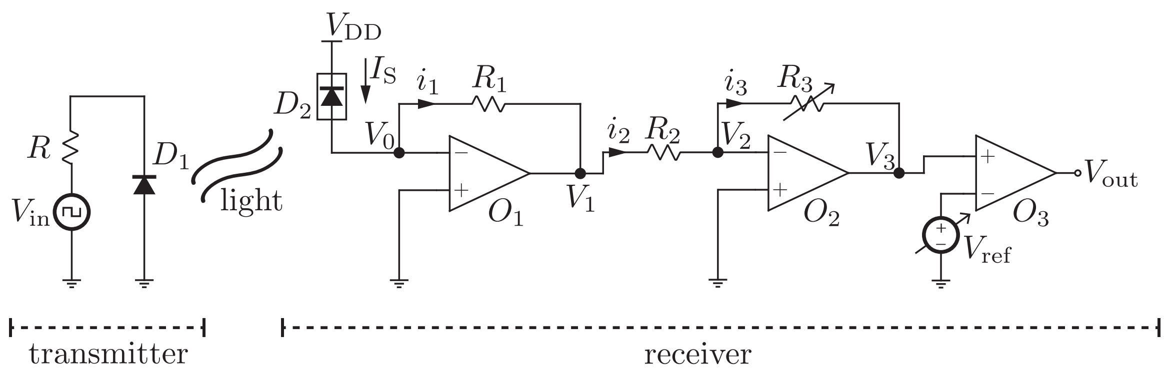
This homework is due November 1, 2016, at 1PM.

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?
   Working in groups of 3-5 will earn credit for your participation grade.

2. **Wireless communication with an LED**

   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.

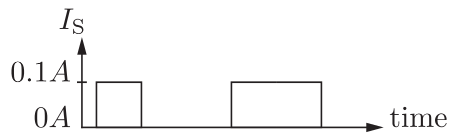
In our system, we define two states for the transmitter, the *transmitter is sending something* when they turn on the LED, and *transmitter is not sending anything* when they turn off the LED. On the receiver side, the goal is to convert the current I_S generated by the solar cell into a voltage and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

3. Island Karaoke Machine

After a plane crash, you're stuck on a desert island and everyone is bored out of their minds. Fortunately you have your EE16 lab kit with op-amps, wires, and resistors, and your handy breadboard. You decide to build a Karaoke machine. You recover one speaker from the crash remains and use your iPhone as your source. You know that many songs put instruments on either "left" or "right" channel, but the vocals are usually present on both channels with equal strength.

The Thevenin equivalent model of the iPhone audio jack and speakers is shown below. For simplicity, we assume that the audio signals V_{Left} and V_{Right} are both DC and that the equivalent source resistance of the left/right audio channels of $R_{Left} = R_{Right} = 3\Omega$. The speaker has an equivalent resistance of 4Ω.

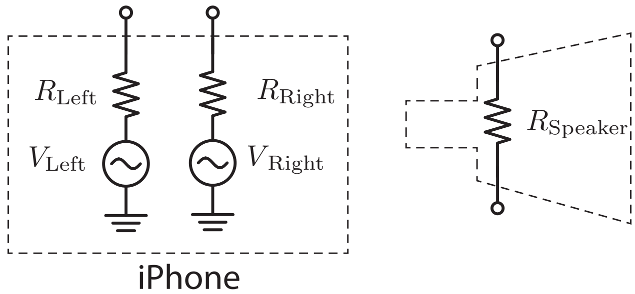
For this problem, we'll assume that

$$V_{Left} = V_{vocals}$$
$$V_{Right} = V_{vocals} + V_{instrument}$$

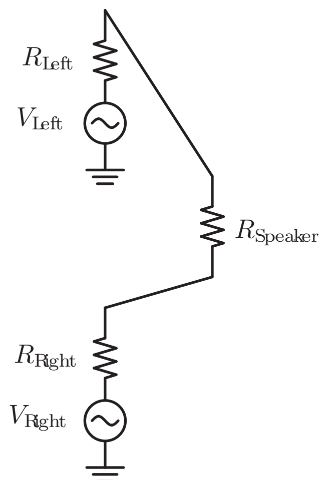
where $V_{vocals} = 120.524mV$ and $V_{instrument} = 50mV$.

That is, the vocals are present on the left and right channel, but the instrument is present only on the right channel.

What is the goal of a karaoke machine? The ultimate goal is to *remove* the vocals from the audio output. We're going to do this by first building a circuit that takes the left and right outputs of the smartphone audio output, and takes its difference. Let's see what happens.



(a) One of your island survivors suggests the following circuit to do this. Calculate the voltage across the speaker. What do you notice? Does the voltage across the speaker depend on V_{vocals}? What do you think the islanders will hear – vocals, instruments, or both?



(b) How much power is delivered to the speaker?

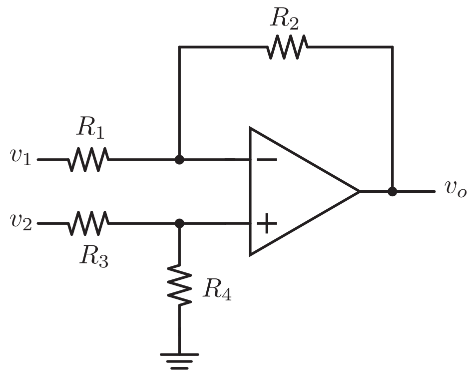
(c) Clearly, we need to boost the sound level to get the party going. We can do this by *amplifying* both V_{Left} and V_{Right}. Keep in mind that we could use the inverting or non-inverting amplifiers from Problem 3 for this – an inverting amplifier has negative gain, and a non-inverting amplifier has positive gain.

Let's assume, just for this part, that all the amplifiers we have produce a gain of 100 (if they are non-inverting), and -100 (if they are inverting). How would you take the difference of the two amplified outputs across the speaker?

(d) Now, design a circuit that takes in V_{Left} and V_{Right}, and outputs an amplified version of $V_{\text{instrument}}$ across the speaker load. You should be able to deliver $1W$ into the speaker load. You can use up to three op-amps, and each of them can be inverting or non-inverting.

(Hint: Use the circuits from problem 3 as building blocks.)

(e) The trouble with the previous part is the number of op-amps required. Let's say you only have one opamp with you. What would you do? One night in your dreams you have an inspiration. Why not combine the inverting and non-inverting amplifier into one, as shown below!



If we set $v_2 = 0V$, what is the gain from v_1 to the output v_o? (this is the inverting path)

(f) If we set $v_1 = 0V$, what is the gain from v_2 to the output v_o? (this is the non-inverting path)

(g) Now, determine v_o in terms of v_1 and v_2. (Hint: use superposition!) Set R_1, R_2, R_3 and R_4 such that, as before, $1W$ is delivered to the speaker load and we don't hear the vocals.

4. **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?