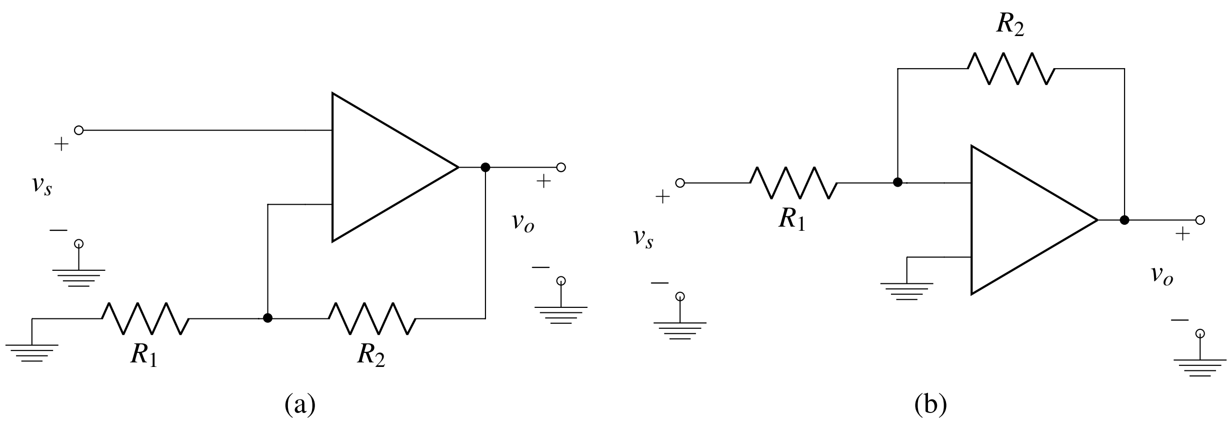
EECS 16A Designing Information Devices and Systems I
Spring 2019 Homework 10

You should plan to complete this homework by Thursday, April 11th. Everything in this homework is in scope for the midterm, but you do not need to turn anything in. There are no self-grades for this homework.

1. Basic Amplifier Building Blocks

The following amplifier stages are used often in many circuits and are well known as (a) the non-inverting amplifier and (b) the inverting amplifier.



(a) Label the input terminals of the op-amp labeled (a), so that it is in negative feedback. Then derive the voltage gain ($A_v = \frac{v_o}{v_s}$) of the non-inverting amplifier using the Golden Rules. Explain the origin of the name of the amplifier.

(b) Label the input terminals of the op-amp labeled (b), so that it is negative feedback. Then derive the voltage gain ($A_v = \frac{v_o}{v_s}$) of the inverting amplifier using the Golden Rules. Explain the origin of the name of the amplifier.

2. Cool For The Summer

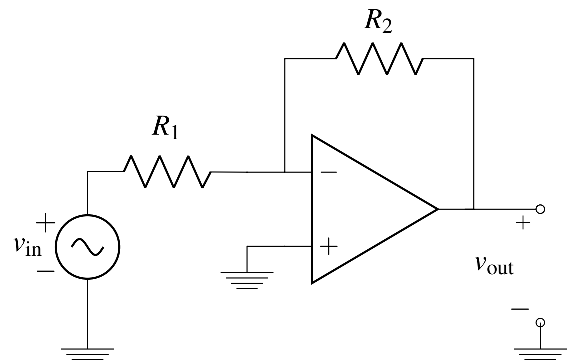
You and a friend want to make a box that helps control an air conditioning unit using both your inputs. You both have individual dials where you can set a control voltage: input of 0 means that you want to leave the temperature as it is. Negative voltage input would mean that you want to reduce the temperature. (It's hot, so we will assume that you never want to increase the temperature – so, we're not talking about a Berkeley summer...)

Your air conditioning unit, however, responds to positive voltages. The higher the magnitude of the voltage, the stronger it runs. At zero, it is off. You also need a system that sums up both you and your friend's control inputs.

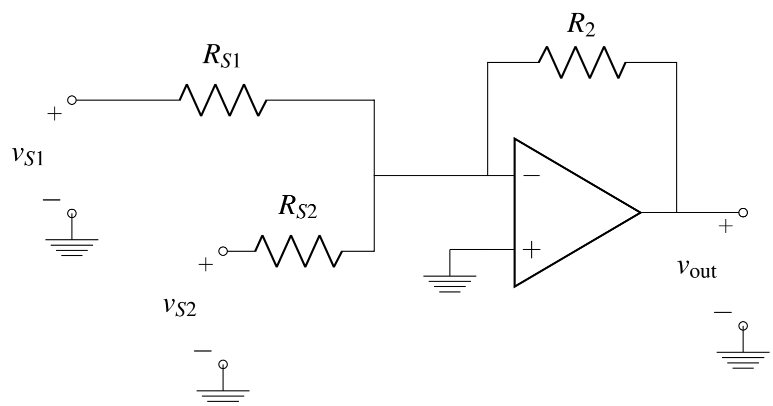
Therefore, you need a box that is **an inverting summer** – *it outputs a weighted sum of two voltages where the weights are both negative*. The sum is weighted because each of you has your own subjective sense of how much to turn the dial down, so you need to compensate for this.

This problem walks you through designing this inverting summer using an op-amp.

(a) As a first step, derive v_{out} in terms of R_2, R_1, v_{in}.



(b) Now we will add a second input to this circuit as shown below. Find v_{out} in terms of v_{S1}, v_{S2}, R_{S1}, R_{S2} and R_2.



(c) Let's suppose that you want $v_{\text{out}} = -\left(\frac{1}{4}v_{S1} + 2v_{S2}\right)$ where v_{S1} and v_{S2} represent the input voltages from you and your friend. Select resistor values such that the circuit implements this desired relationship.

(d) Now suppose that you have a new AC unit that you want to use with your control inputs v_{S1} and v_{S2}. This unit, however, functions opposite to the previous unit; it responds to negative voltages. The higher the magnitude of the negative voltage, the stronger the AC runs.
Now design a circuit that *outputs a weighted sum of two control input voltages where both weights are positive*. Specifically, add another op-amp based circuit to your circuit in part (b), so that you invert the output of the circuit from part (b).

3. Island Karaoke Machine

You're stuck on a desert island and everyone is bored out of their minds. Fortunately, you have your EE16A lab kit with op-amps, wires, 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 the "left" or the "right" channel, but the vocals are usually present on both channels with equal strength.

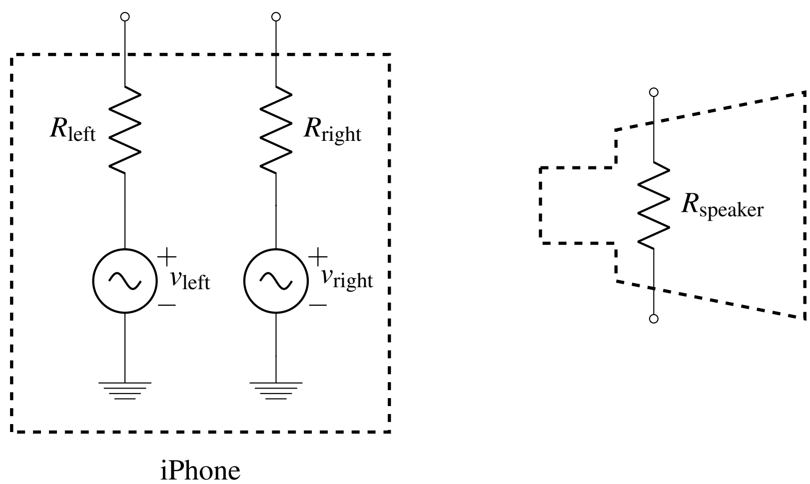
The Thevenin equivalent model of the iPhone audio jack and speakers is shown below. We assume that the audio signals v_{left} and v_{right} have equivalent source resistance of the left/right audio channels of $R_{\text{left}} = R_{\text{right}} = 3\,\Omega$. The speaker has an equivalent resistance of $R_{\text{speaker}} = 4\,\Omega$.

For this problem, we'll assume that the vocals are present on both left and right channels, but the instruments are only present on the right channel, i.e.

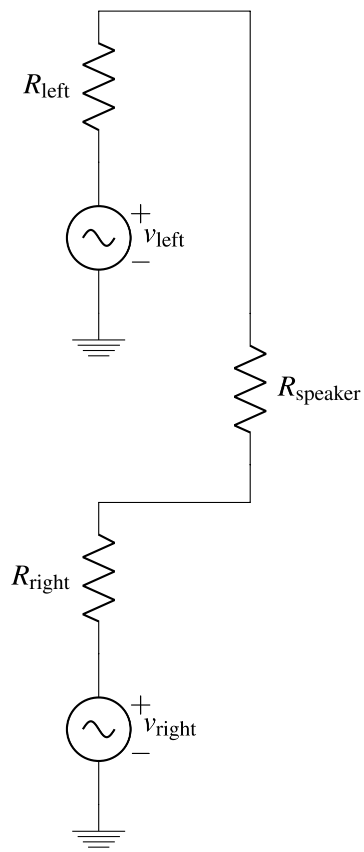
$$v_{\text{left}} = v_{\text{vocals}}$$
$$v_{\text{right}} = v_{\text{vocals}} + v_{\text{instrument}},$$

where the voltage source v_{vocals} can have values anywhere in the range of $\pm 120\,\text{mV}$ and $v_{\text{instrument}}$ can have values anywhere in the range of $\pm 50\,\text{mV}$.

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 audio outputs of the smartphone and then calculates 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 as a function of v_{vocals} and $v_{\text{instruments}}$.
Does the voltage across the speaker depend on v_{vocals}? What do you think the islanders will hear – vocals, instruments, or both?



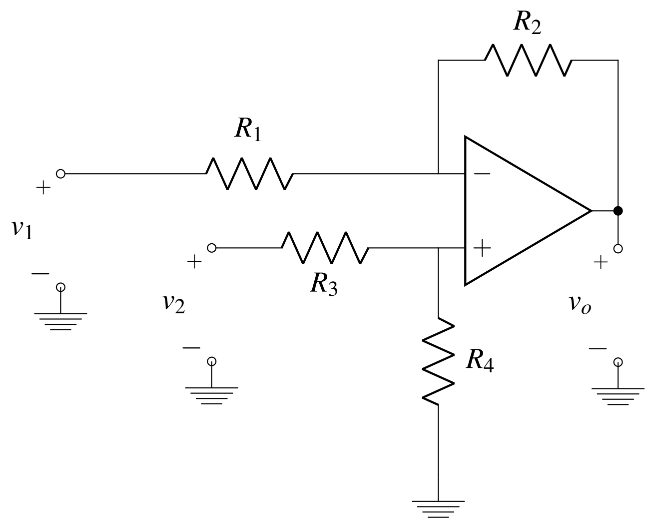
(b) We need to boost the sound level to get the party going. We can do this by *amplifying* both v_{left} and v_{right}. Keep in mind that we could use inverting or non-inverting amplifiers.

Let's assume, just for this part, that we have already implemented circuits that amplify v_{left} and v_{right} by some factor A_v (Consider $A_v = 100$ for this part). We now have two voltages, v_{Gl} and v_{Gr} that are $A_v \cdot v_{\text{left}}$ and $A_v \cdot v_{\text{right}}$ respectively. Use v_{Gl} and v_{Gr} to get $A_v \cdot v_{\text{instrument}}$ across R_{speaker}.

(c) Now, you want $\pm 2\,\text{V}$ across the speaker to get the party going. Using the scheme in part (b), design a circuit that takes in v_{left} and v_{right} and outputs an amplified version of $v_{\text{instrument}}$ across the speaker with the range of $\pm 2\,\text{V}$. You need to design both amplifiers with the right gain A_v to achieve this.

You can use up to two op-amps, and each of them can be inverting or non-inverting.

(d) The trouble with the approach in part (c) is that multiple op-amps are required. Let's say you only have one op-amp 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!



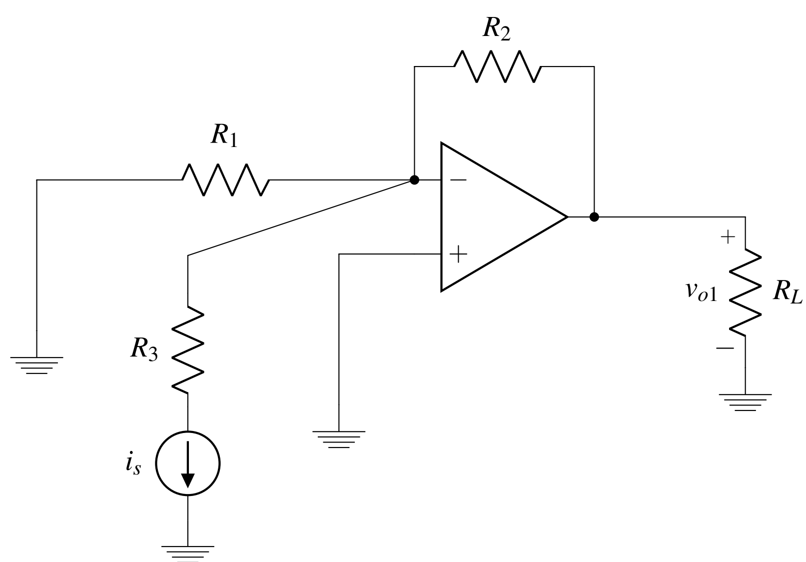
If we set $v_2 = 0\,\text{V}$, what is the output v_o in terms of v_1? (This is the inverting path.)

(e) If we set $v_1 = 0\,\text{V}$, what is the output v_o in terms of v_2? (This is the non-inverting path.)

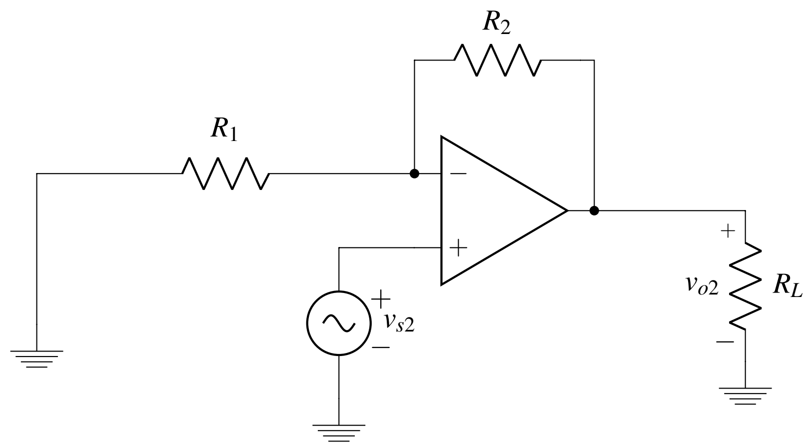
(f) Now, determine v_o in terms of v_1 and v_2. (*Hint:* Use superposition.) Choose values for R_1, R_2, R_3 and R_4, such that the speaker has $\pm 2\,\text{V}$ across it.

4. Amplifier with Multiple Inputs

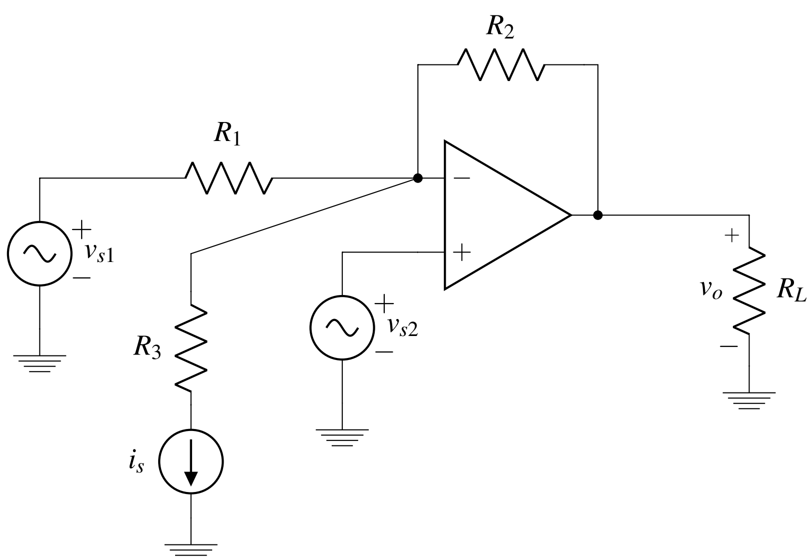
(a) Use the Golden Rules to find v_{o1} for the circuit below.



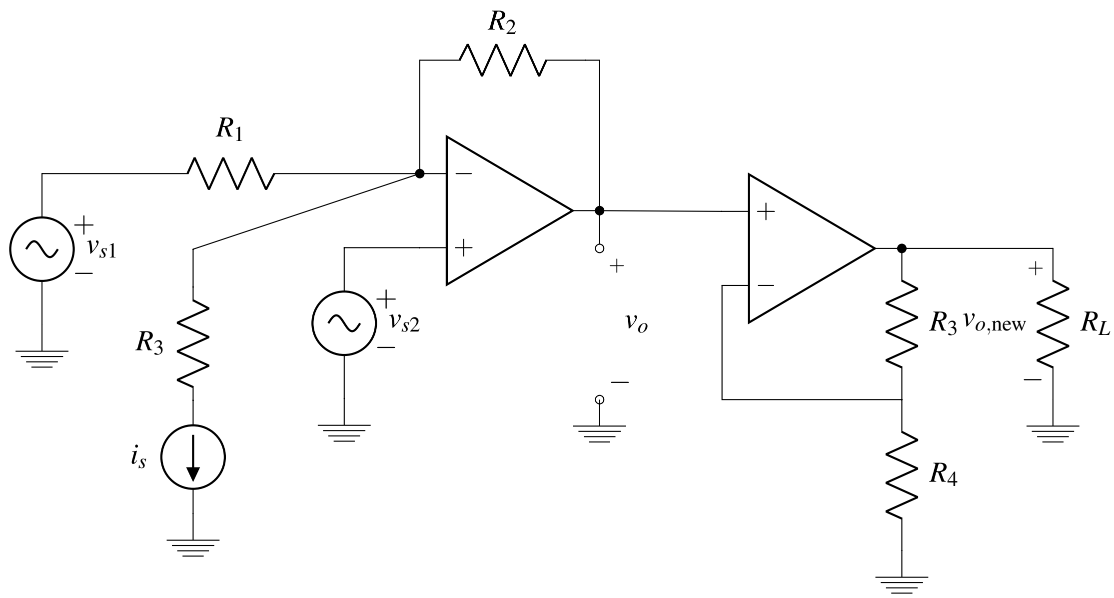
(b) Use the Golden Rules to find v_{o2} for the circuit below.



(c) Use the Golden Rules to find the output voltage v_o for the circuit shown below.



(d) Now add a second stage as shown below. What is $v_{o,\text{new}}$? Does v_o change between part (c) and this part? Does the voltage $v_{o,\text{new}}$ depend on R_L?



5. Homework Process and Study Group

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