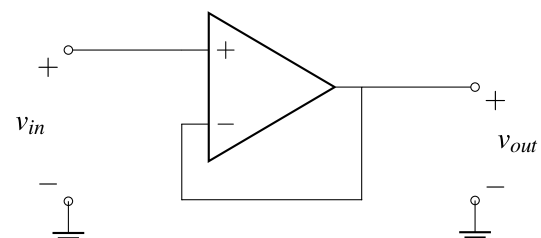
EECS 16A Designing Information Devices and Systems I
Spring 2022 Discussion 10B

1. Testing for Negative Feedback

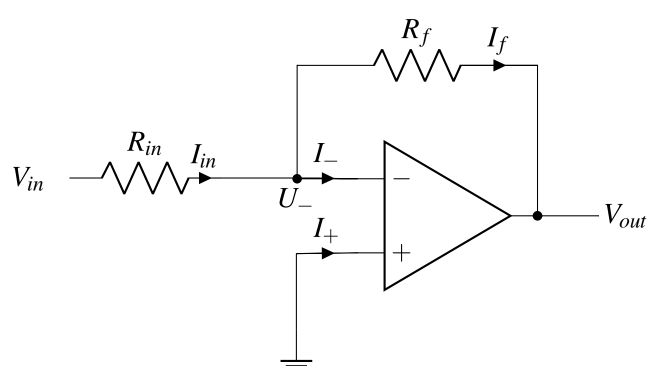
While it is tempting to say "if the feedback voltage is connected to the negative op-amp terminal, then we have negative feedback," this is not always true. Here is a two-step procedure for determining if a circuit is in negative feedback:

- **Step 1: Zero out all independent sources**, replacing voltage sources with wires and current sources with opens as we did in superposition. You do not need to zero out the voltage sources that serve as the power supplies to the op-amp, since they are not treated as signals and almost considered part of the op-amp.
- **Step 2: Wiggle the output and check the loop**. Assume that the output increases slightly. Check the direction of change of the feedback signal and the error signal from the circuit. Any change in the error signal will cause a new change in the output. This change is the feedback loop's response to the initial change.
  - If the error signal decreases, then the output must also decrease. This is the *opposite direction* we initially assumed, i.e. the loop is trying to correct for the change. So the circuit is in negative feedback.
  - If the error signal instead increased, then the output would also increase. This is the *same direction* we initially assume, i.e. the initial increase lead to further increase. We call this positive feedback.

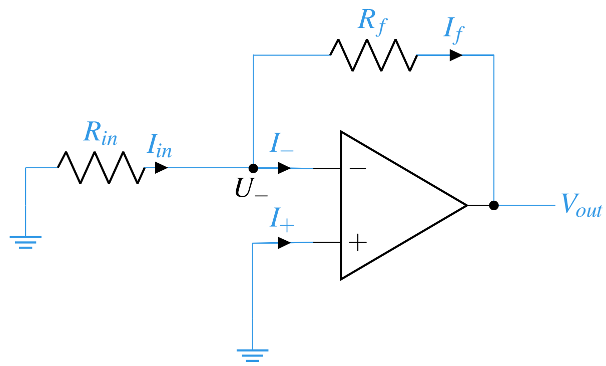
(a) Show that the voltage buffer circuit is in negative feedback. Note that here v_{in} is acting as a voltage source.



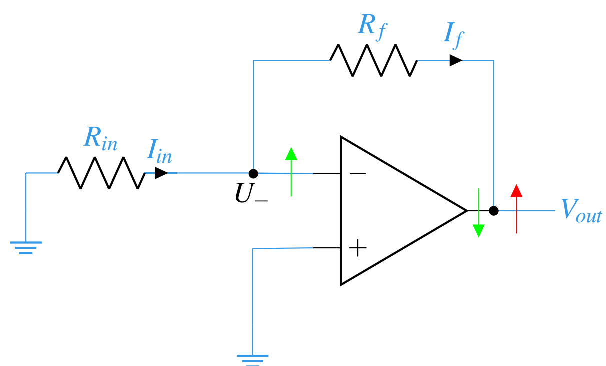
(b) Show that the inverting amplifier circuit is in negative feedback.



Solution/Answer: First, zero out all independent sources. For this problem, we just need to tie the input to ground.



Note that R_f and R_{in} now form a voltage divider.
Next, wiggle the output and check the loop. Below, we label the initial change in the output in red and label subsequent changes in green:



We suppose that the v_{out} goes up. v_{out} is connected to U_- so U_- also goes up. Our op-amp equation is $v_{out} = A(v_+ - v_-)$, so U_- going up will cause v_{out} to go down. This is the opposite of what initially happened, so we are in negative feedback.

2. Transresistance Amplifier

A common use of an op-amp is to convert a current signal into a voltage signal. This configuration is called a *transresistance amplifier*, as shown in Fig. 1. (Note: In the real world, we call this a trans*impedance* amplifier. Impedance is just a fancy word to describe resistance as a function of frequency.) Assume that $V_{SS} = -V_{DD}$ for all the parts of this problem.

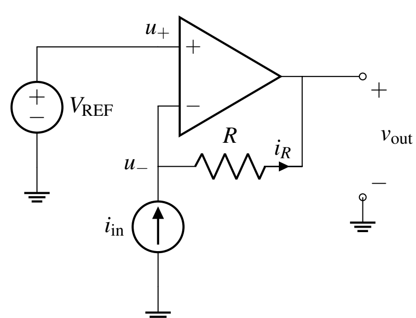


Figure 1: Transresistance amplifier

(a) What is the value of the current i_R in Fig. 1? *Hint: Your answer should be in terms of i_{in}.*

Answer: By the Golden Rules, since there is no current flowing into the negative terminal of the op-amp, all the current from the current source flows through the feedback resistor. Therefore, $i_R = i_{\text{in}}$.

(b) What is the voltage at the negative terminal of the op-amp u_- in terms of V_{REF}.

Answer: Note that this op-amp is in negative feedback. Therefore, by the Golden Rules, the voltages at the negative and positive terminals of the op-amp are equal. Thus, the voltage at the negative terminal of the op-amp is V_{REF}

(c) Using the results from parts (a) and (b), find an expression of v_{out} in terms of V_{REF}, i_{in}.

Answer: We can write a single KCL equation at the negative input terminal of the op-amp as follows:

$$i_{\text{in}} = \frac{V_{\text{REF}} - v_{\text{out}}}{R}$$
$$\implies v_{\text{out}} = V_{\text{REF}} - i_{\text{in}} R$$

(d) If we set $V_{\text{REF}} = 0\,\text{V}$, calculate the gain of the overall circuit $G = \frac{v_{\text{out}}}{i_{\text{in}}}$.

Answer: Note that in this configuration, the input signal is current i_{in} (*aside: contrast this with other op-amp circuit examples that you have seen in which the input is typically a voltage*), and the output signal is voltage v_{out}. Therefore, in this case, you will want to report the gain of this circuit as $\frac{v_{\text{out}}}{i_{\text{in}}}$.

$$\text{Gain} = \frac{v_{\text{out}}}{i_{\text{in}}} = \frac{-i_{\text{in}} R}{i_{\text{in}}} = -R$$

3. (Practice: Modular Op-Amp Circuits)

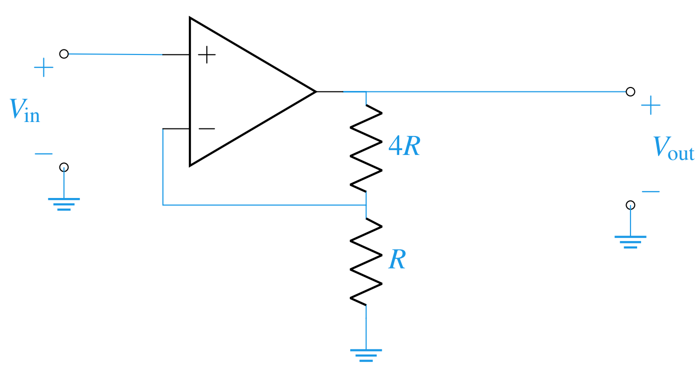
Let's design blocks that implement the following operations

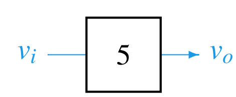
(a) Scale the input voltage so that: $V_{\text{out}} = +5\ V_{\text{in}}$

(b) Scale and invert the input voltage so that: $V_{\text{out}} = -2\ V_{\text{in}}$

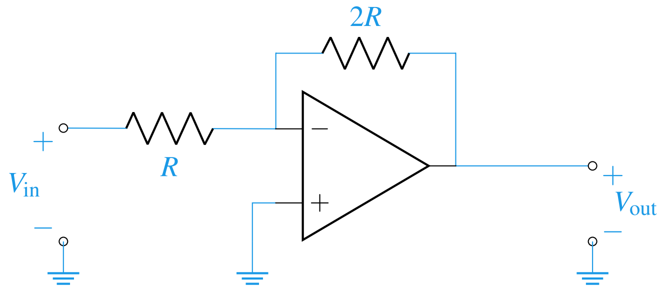
Answer:

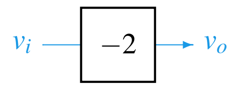
(a) Since our scaling of $+5$ is positive, we employ a non-inverting amplifier without a V_{REF} supply:



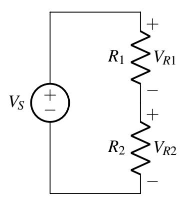
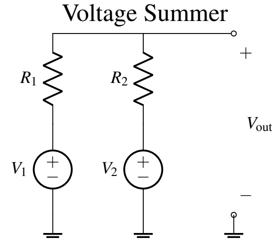
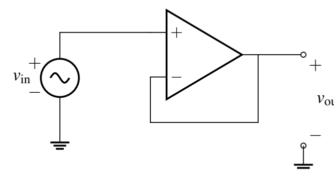
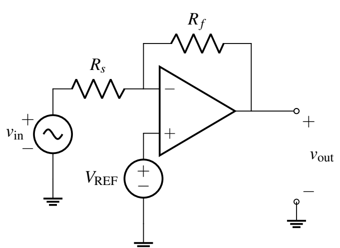
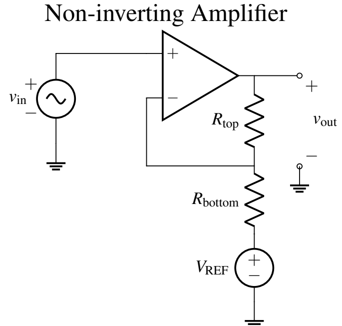
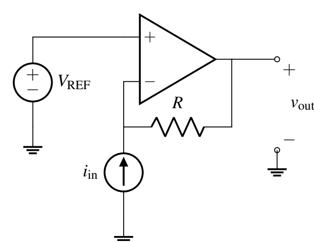


(b) To scale the input by -2 we must use the inverting amplifier configuration:





(For Reference: Example Circuits)

Voltage Divider  $V_{R2} = V_S\left(\frac{R_2}{R_1+R_2}\right)$	Voltage Summer  $V_{\text{out}} = V_1\left(\frac{R_2}{R_1+R_2}\right) + V_2\left(\frac{R_1}{R_1+R_2}\right)$	Unity Gain Buffer  $\frac{v_{\text{out}}}{v_{\text{in}}} = 1$
Inverting Amplifier  $v_{\text{out}} = v_{\text{in}}\left(-\frac{R_f}{R_s}\right) + V_{\text{REF}}\left(\frac{R_f}{R_s}+1\right)$	Non-inverting Amplifier  $v_{\text{out}} = v_{\text{in}}\left(1+\frac{R_{\text{top}}}{R_{\text{bottom}}}\right) - V_{\text{REF}}\left(\frac{R_{\text{top}}}{R_{\text{bottom}}}\right)$	Transresistance Amplifier  $v_{\text{out}} = i_{\text{in}}(-R) + V_{\text{REF}}$

