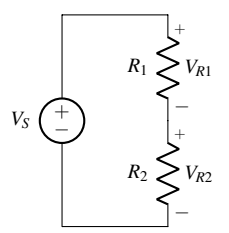
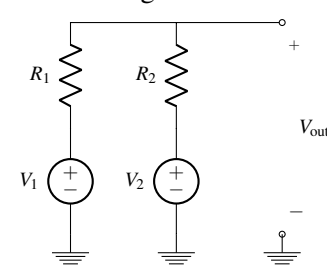
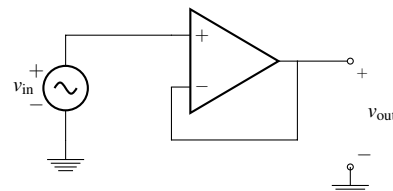
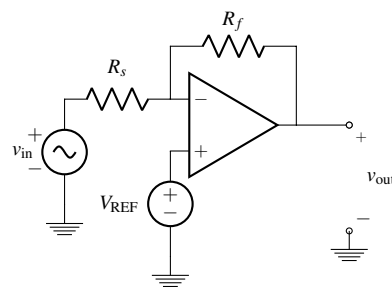
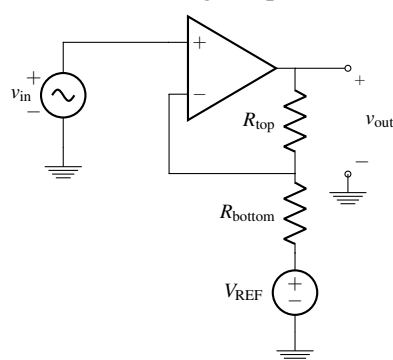
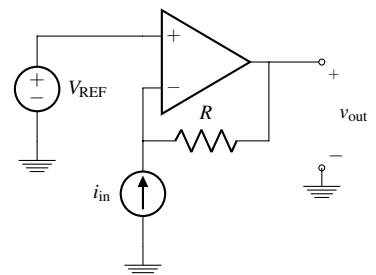


EECS 16A Designing Information Devices and Systems I

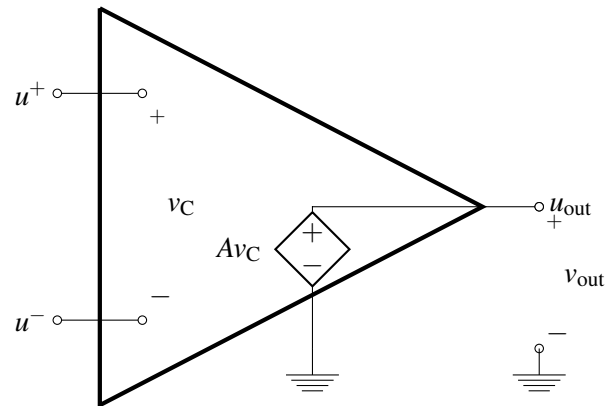
Discussion 10B

For Reference: Example Circuits

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

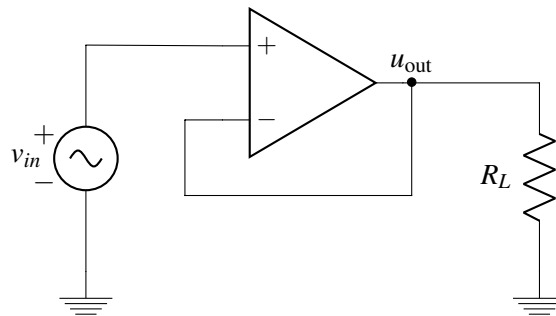
1. Op-Amp Rules and Negative Feedback Rule

Here is an equivalent circuit of an op-amp (where we are assuming that $V_{SS} = -V_{DD}$) for reference:



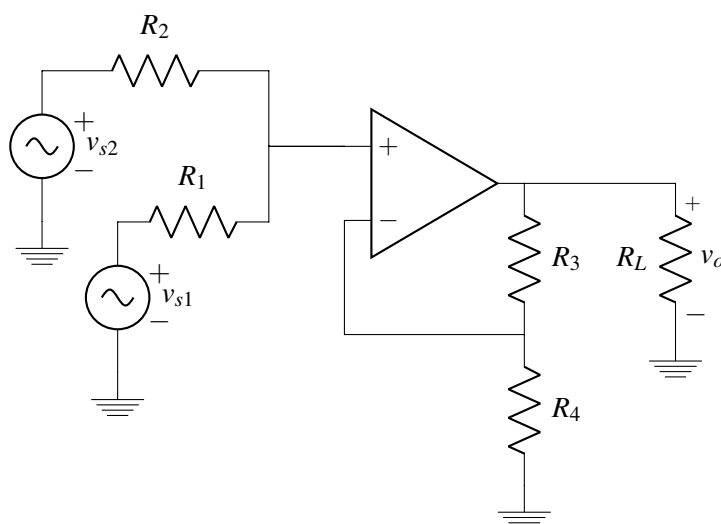
- What are the currents flowing into the positive and negative terminals of the op-amp (i.e., what are I^+ and I^-)? What are some of the advantages of your answer with respect to using an op-amp in your circuit designs?
- Suppose we add a resistor of value R_L between u_{out} and ground. What is the value of v_{out} ? Does your answer depend on R_L ? In other words, how does R_L affect Av_C ? What are the implications of this with respect to using op-amps in circuit design?

For the rest of the problem, consider the following op-amp circuit in negative feedback:



- Assuming that this is an ideal op-amp, what is v_{out} ?
- Draw the equivalent circuit for this op-amp and calculate v_{out} in terms of A , v_{in} , and R_L for the circuit in negative feedback. Does v_{out} depend on R_L ? What is v_{out} in the limit as $A \rightarrow \infty$?

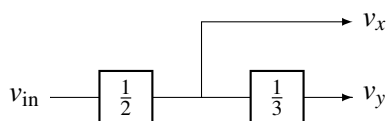
2. Multiple Inputs To One Op-Amp



- (a) For the circuit above, find an expression for v_o . (*Hint: Use superposition.*)
 (b) How could you use this circuit to find the sum of different signals?

3. Modular Circuits

In this problem, we will explore the design of circuits that perform a set of (arbitrary) mathematical operations in order to elucidate some of the important properties and uses of op-amps in negative feedback. In the last discussion, we noticed that voltage dividers are not compose-able, so we will use op-amps instead. Again, recall that we want to implement the block diagram shown below:



In other words, we want to implement a circuit with two outputs v_x and v_y , where $v_x = \frac{1}{2}v_{in}$ and $v_y = \frac{1}{3}v_x$.

- (a) Using an ideal op-amp in negative feedback, modify the design of one of the two voltage divider circuits you built (i.e. the $\frac{1}{2}$ block or the $\frac{1}{3}$ block), so that the originally intended relationships between v_x and v_{in} as well as v_y and v_x are realized by the resulting overall circuit (where each block is replaced by its individual implementation). Is this configuration enough by itself to attach loads at v_x and v_y ?
- (b) Now let's assume that we want to expand our toolbox of circuits that implement mathematical operations. In particular, design blocks that implement:
- $v_o = 5v_i$
 - $v_o = -2v_i$
 - $v_o = v_{i1} + v_{i2}$

Pay careful attention to the way you design these blocks, so that connecting any one block to any other block does not modify the intended functionality of any of the blocks.