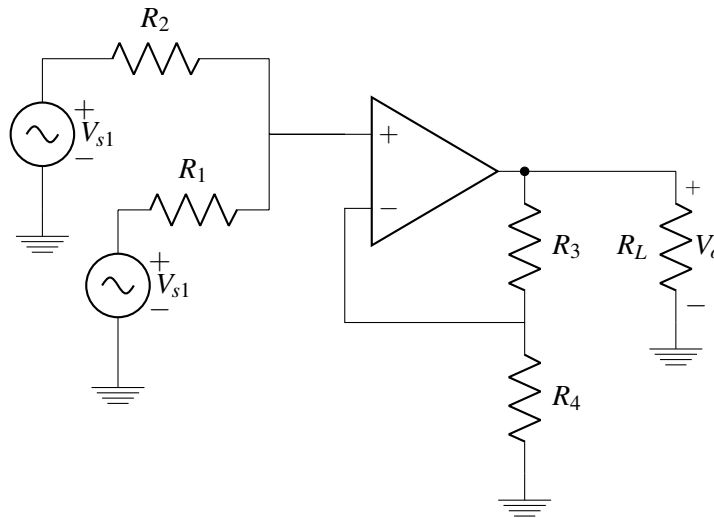


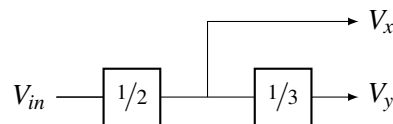
### 1. Multiple Inputs to One Op Amp



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

### 2. 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. (Note that the so-called analog signal processing - where these kinds of mathematical operations are performed on continuously-valued voltages by analog circuits - is extremely common in real-world applications; without this capability, essentially none of our e.g. radios or sensors would actually work.) Specifically, let's assume 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  $V_y = \frac{1}{3}V_x$ .

- Design two voltage divider circuits that each independently would implement the two multiplications shown in the block diagram above (i.e., multiply by  $1/2$ , and multiply by  $1/3$ ). Note that you do not need to include the input voltage sources in your design – you can simply define the input to each block as being at the appropriate potential (e.g.,  $V_{in}$  or  $V_x$ ).

- (b) Assuming that  $V_{in}$  is created by an ideal voltage source, implement the original block diagram as a circuit by directly replacing each block with the designs you came up with in part (a).
- (c) For the circuit from part (b), do you get the desired relationship between  $V_y$  and  $V_x$ ? How about between  $V_x$  and  $V_{in}$ ? Be sure to explain why or why not each block retains its desired functionality.
- (d) Using an ideal op-amp in negative feedback, modify the design of one of the two blocks (i.e. the  $1/2$  block or the  $1/3$  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  $V_y$ ?
- (e) Now let's assume that we want to expand our toolbox of circuits that implement mathematical operations. In particular, design blocks that implement:
- $V_o = 5V_i$
  - $V_o = -2V_i$
  - $V_o = V_{i_1} + V_{i_2}$

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.

- (f) Check that your designs from part (e) indeed enable a library of compose-able elements (i.e. that you can connect any block to any other block without having the intended functionality be modified) by implementing the block diagram shown below.

