EECS 16A Designing Information Devices and Systems I
Spring 2023 Discussion 11A

1. Unity Gain Feedback

Below is the general block diagram for negative feedback where A represents the gain of our system and f is the feedback factor.

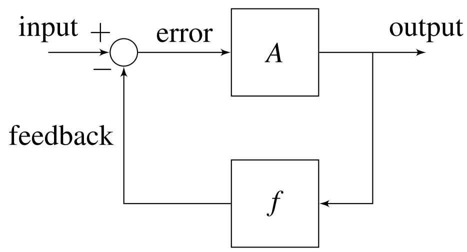


Figure 1: Block diagram for negative feedback.

In this problem, we will look at a specific and important case where $f = 1$, also known as unity gain feedback.

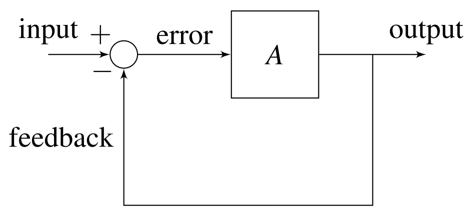


Figure 2: Block diagram for unity gain feedback.

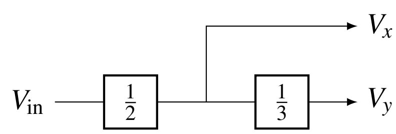
(a) What is the transfer function (ratio of output to input) of the unity gain feedback system? What happens when the system gain is very large, i.e. $A \to \infty$.

(b) How can we implement the unity-gain feedback system using a single op-amp?

(c) Although the gain of an op-amp is very large (usually in the tens or hundreds of thousands), it is very difficult to precisely control the gain during manufacturing. Assume we have three op-amps which have different gains of $A = 50\,000, 75\,000, 100\,000$. For each value of A, what is the resulting transfer function of the op-amp in unity-gain configuration? What is an advantage of placing an op-amp in negative feedback?

2. Modular Circuit Buffer

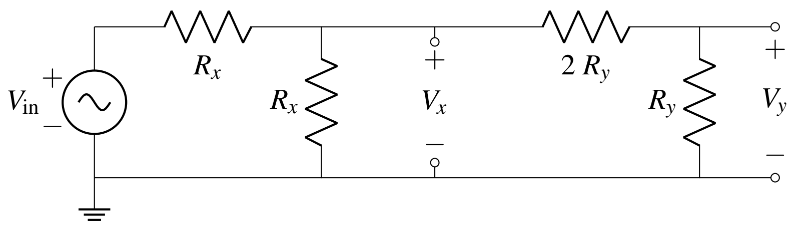
Let's try designing circuits that perform a set of mathematical operations using op-amps. While voltage dividers on their own cannot be combined without altering their behavior, op-amps can preserve their behavior when combined and thus are a perfect tool for modular circuit design. We would like to implement the block diagram shown below:



In other words, create a circuit with two outputs V_x and V_y, where $V_x = \frac{1}{2}V_{\text{in}}$ and $V_y = \frac{1}{3}V_x = \frac{1}{6}V_{\text{in}}$.

(a) Draw two voltage dividers, one for each operation (the $1/2$ and $1/3$ scalings). What relationships hold for the resistor values for the $1/2$ divider, and for the resistor values for the $1/3$ divider?

(b) If you combine the voltage dividers, made in part (a), as shown by the block diagram (output of the $1/2$ voltage divider becomes the source for the $1/3$ voltage divider circuit), do they behave as we hope (meaning $V_{\text{in}} = 2V_x = 6V_y$)?



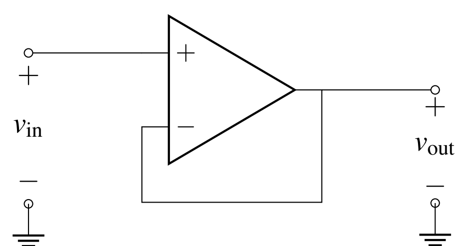
(c) Perhaps we could use an op-amp (in negative-feedback) to achieve our desired behavior.
Modify the implementation you tried in part (b) using a negative feedback op-amp in order to achieve the desired V_x, V_y relations $V_x = \frac{V_{\text{in}}}{2}$ and $V_y = \frac{V_x}{3} = \frac{V_{\text{in}}}{6}$.
HINT: Place the op-amp in between the dividers such that the V_x node is an input into the op-amp, while the source of the 2nd divider is the output of the op-amp!

3. 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 are not 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.