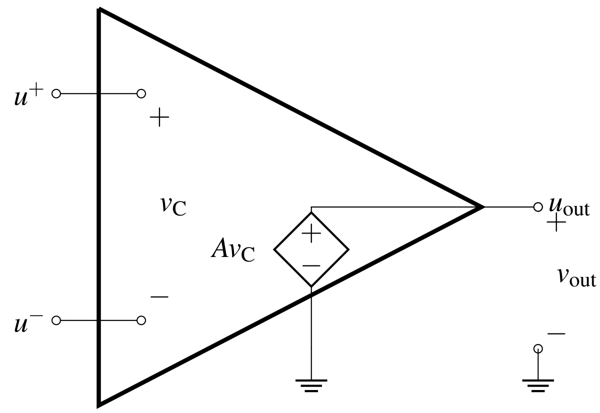
EECS 16A Designing Information Devices and Systems I
Spring 2019 Discussion 10B

1. Op-Amp Rules and Negative Feedback Rules

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



(a) What are the currents flowing into the positive and negative terminals of the op-amp (i.e., what are I^+ and I^-)? Based on this answer, what are some of the advantages of using an op-amp in your circuit designs?

Answer:

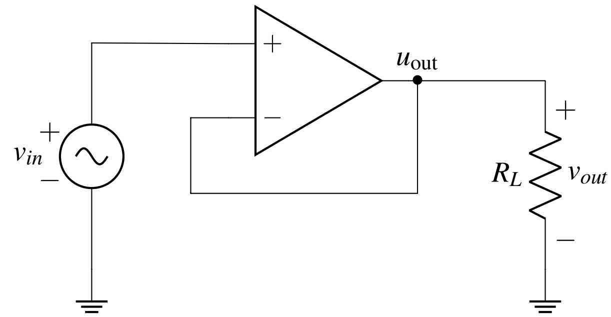
The u^+ and u^- terminals have no closed circuit connection between them, and therefore no current can flow into or out of them. This is very good because we can connect an op-amp to any other circuit, and the op-amp will not disturb that circuit in any way because it does not load the circuit (it is an open circuit).

(b) 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?

Answer:

Notice that u_{out} is connected directly to a controlled/dependent voltage source, and therefore v_{out} will always have to be equal to Av_C regardless of what R_L is connected to the op-amp. This is very advantageous because it means that the output of the op-amp can be connected to any other circuit (except a voltage source), and we will always get the desired/expected voltage out of the op-amp.

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



(c) Assuming that this is an ideal op-amp, what is v_{out}?

Answer:

Recall for an ideal op-amp in negative feedback, we know from the negative feedback rule that $u^+ = u^-$. In this case, $u^- = u_{\text{out}} = u^+$.

(d) 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 $A \to \infty$?

Answer:

Notice that the op-amp can be modeled as a voltage-controlled voltage source. Thus, we have the following equation:

$$v_{\text{out}} = A(v_{in} - v_{\text{out}})$$
$$v_{\text{out}} + Av_{\text{out}} = Av_{in}$$
$$v_{\text{out}} = v_{in}\frac{A}{1+A}$$

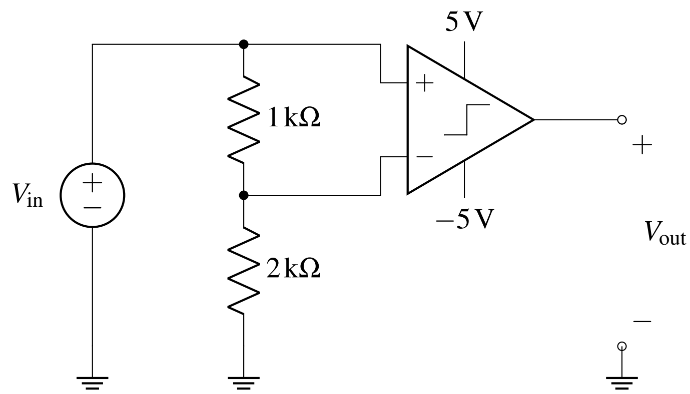
Thus, as $A \to \infty$, $v_{\text{out}} \to v_{\text{in}}$. This is the same as what we get after applying the op-amp rule.

Notice that output voltage does not depend on R. Thus, this circuit acts like a voltage source that provides the same voltage read at u^+ without drawing any current from the terminal at u^+. This is why the circuit is often referred to as a "unity gain buffer," "voltage follower," or just "buffer."

2. Comparators

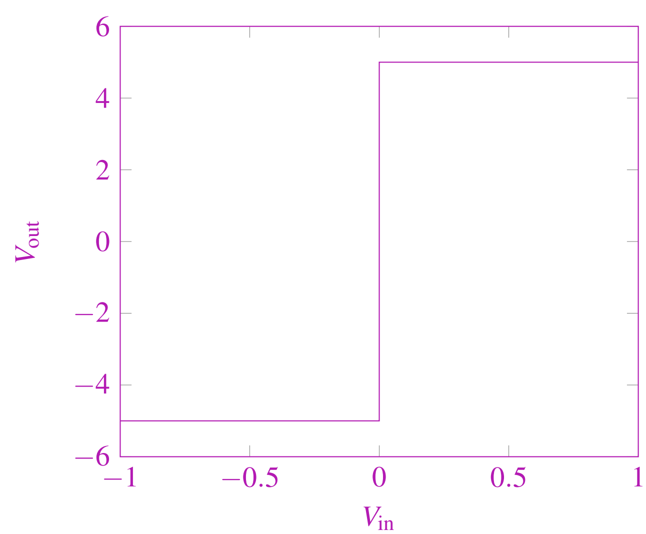
For each of the circuits shown below, plot V_{out} for V_{in} ranging from $-10\,V$ to $10\,V$ for part (a) and from $0\,V$ to $10\,V$ for part (b).

(a)

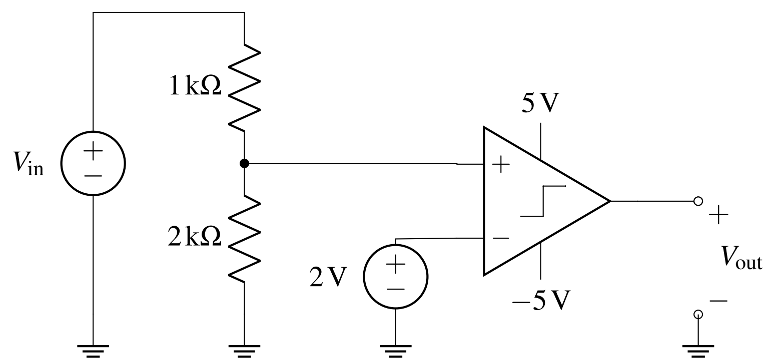


Answer:

When the positive terminal's voltage, V_+, is greater than the negative terminal's voltage, V_-, the value at the positive supply rail, V_{DD},will be output. Likewise, if the negative terminal's voltage, V_-, has a higher voltage then the value at the negative supply rail, V_{SS}, will be output. Since V_- is just the output of a voltage divider with the source $V_{in} = V_+$, it will always have lower absolute value and same polarity as the positive terminal. Thus, the comparator's output will depend only on the sign of the source V_{in}.



(b)



Answer:

$$V_+ = \frac{2\,\text{k}\Omega}{1\,\text{k}\Omega + 2\,\text{k}\Omega} V_{\text{in}} = \frac{2}{3} V_{\text{in}}$$

$$V_- = 2\,\text{V}$$

The comparator will output positive 5V when the voltage divider's output $V_+ > 2\,\text{V}$ and thus when $V_{\text{in}} > 3\,\text{V}$. Otherwise, it will output -5V.