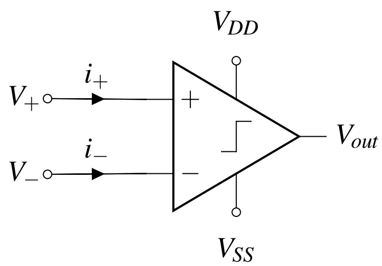
CSM 16A Designing Information Devices and Systems I
Fall 2020 Week 9

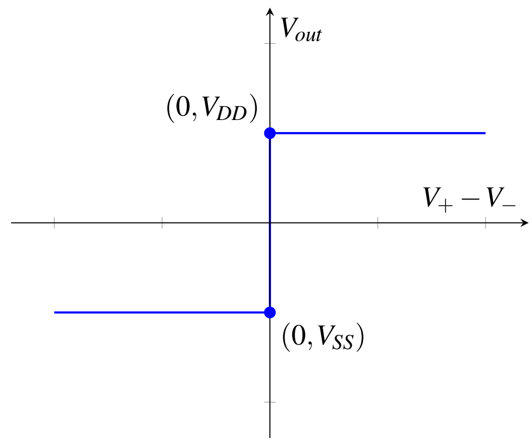
1. **Comparators**

Learning Goal: This problem will help to understand comparator properties and design circuits with comparators.

Relevant Notes: Note 17C goes over comparator properties.

Comparators are typically drawn like the figure on the left, and their internal workings can be represented by the figure on the right.

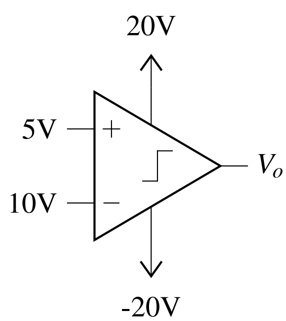




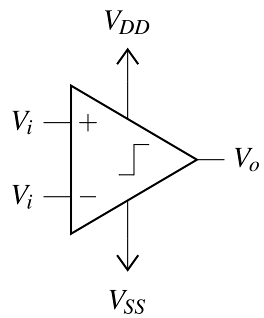
Here, V_+ and V_- are input voltages, V_{DD} and V_{SS} are what we call the "supply rails", and V_{out} is the output voltage. From the diagram and knowing that V_{out} cannot exceed the supply rail voltages, we have a relationship between the outputs and the inputs:

$$V_{out} = \begin{cases} V_{DD} & \text{, if } \quad V_+ > V_-) \\ V_{SS} & \text{, if } \quad V_+ < V_-) \\ \text{undefined} & \text{, if } \quad V_+ = V_-) \end{cases}$$

(a) Identify the output voltage V_o for the following comparator:

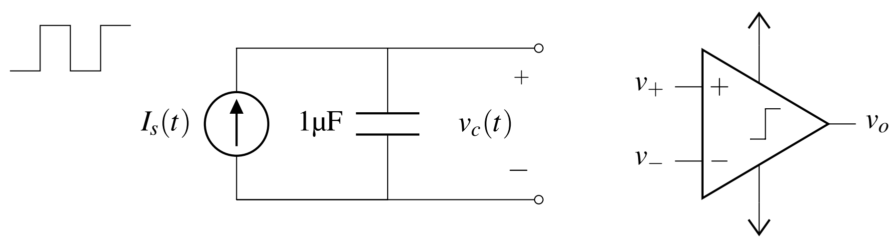


(b) Identify the output voltage V_o for the following comparator:

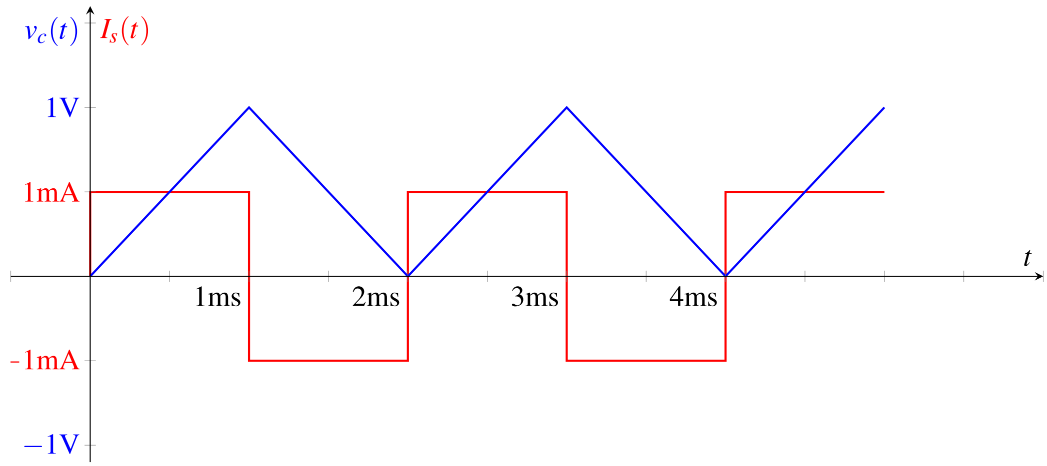


(c) Design a circuit by connecting the capacitive circuit and the comparator in the following figure such that $v_o = 2\text{V}$ if $v_c > 0.5\text{V}$ and $v_o = -1\text{V}$ if $v_c < 0.5\text{V}$. Draw your designed circuit.

You can use as many voltage sources you want. Label the values of the voltage sources you use.



(d) Assume $I_s(t)$ and $v_c(t)$ are given in the following figure. Plot $v_o(t)$ vs. time for the circuit you designed in the last part.



(e) Redesign your circuit such that $v_o = -2\text{V}$ if $v_c > 0.5\text{V}$ and $v_o = 1\text{V}$ if $v_c < 0.5\text{V}$. Draw your redesigned circuit.

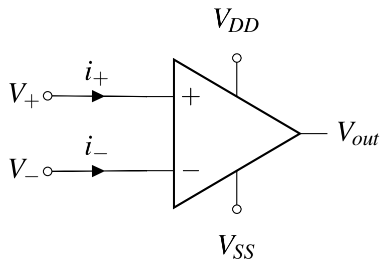
You can use as many voltage sources you want. Label the values of the voltage sources you use.

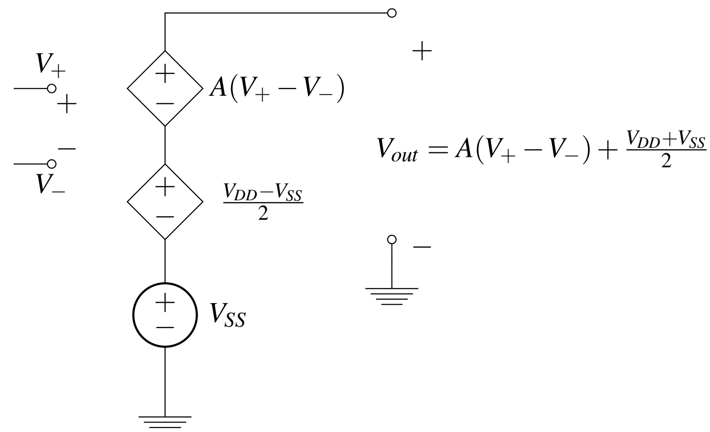
2. Operational Amplifiers

Learning Goal: This problem will help to understand op-amps in negative feedback and the operation of an inverting amplifier.

Relevant Notes: **Note 18** goes over op-amp properties and derivation of circuit responses.

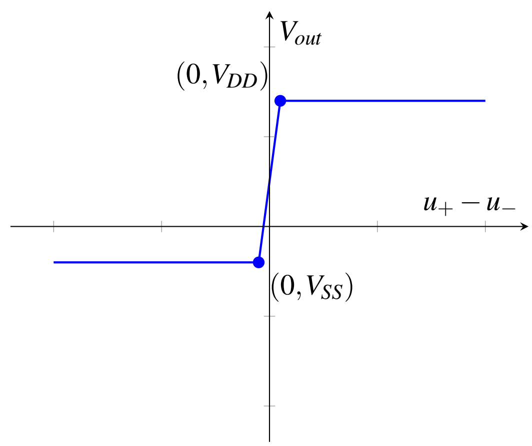
Operational amplifiers (op amps for short) are typically drawn like the figure on the left, and their internal workings can be represented by the figure on the right.





Here, V_+ and V_- are input voltages, V_{DD} and V_{SS} are what we call the "supply rails", and V_{out} is the output voltage. From the diagram and knowing that V_{out} cannot exceed the supply rail voltages, we have a relationship between the outputs and the inputs:

$$V_{out} = \begin{cases} V_{SS} & \text{, if} \quad A(V_+ - V_-) + \frac{V_{DD}+V_{SS}}{2} < V_{SS} \\ A(V_+ - V_-) + \frac{V_{DD}+V_{SS}}{2} & \text{, if} \quad V_{SS} \leq A(V_+ - V_-) + \frac{V_{DD}+V_{SS}}{2} \leq V_{DD} \\ V_{DD} & \text{, if} \quad V_{DD} < A(V_+ - V_-) + \frac{V_{DD}+V_{SS}}{2} \end{cases}$$

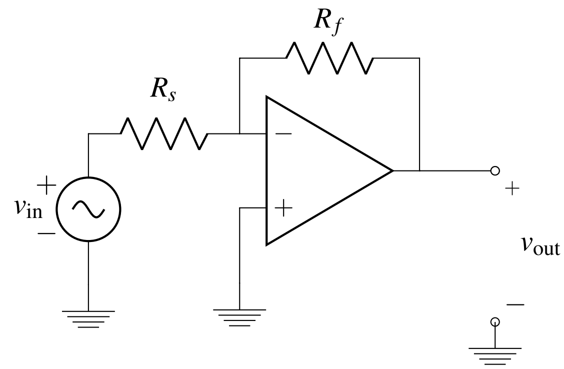


Typically gain A is quite large, meaning the the sloped region in the center is quite narrow.

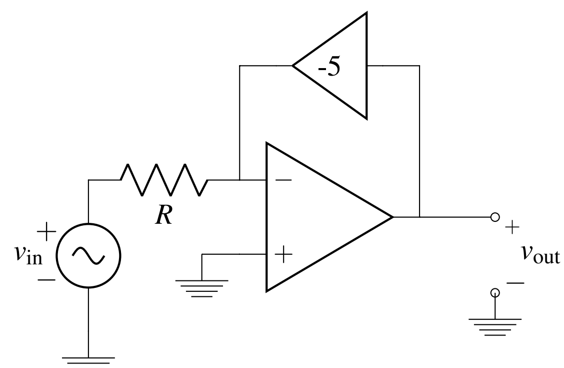
(a) Much of EE16A will have our analysis be restricted to ideal op-amps. However, it is important to know non-ideal behaviors. What are some main differences between ideal and non-ideal op-amps?

(b) If the gain of an operational amplifier/op amp is given by $A \to \infty$, so we can make some assumptions known as the "Golden Rules". What are the "Golden Rules" and when are they applicable?

(c) Determine if the following system is in negative feedback.

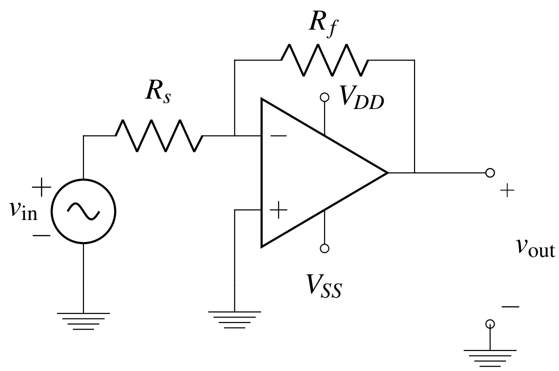


(d) Determine if the following system is in negative feedback.

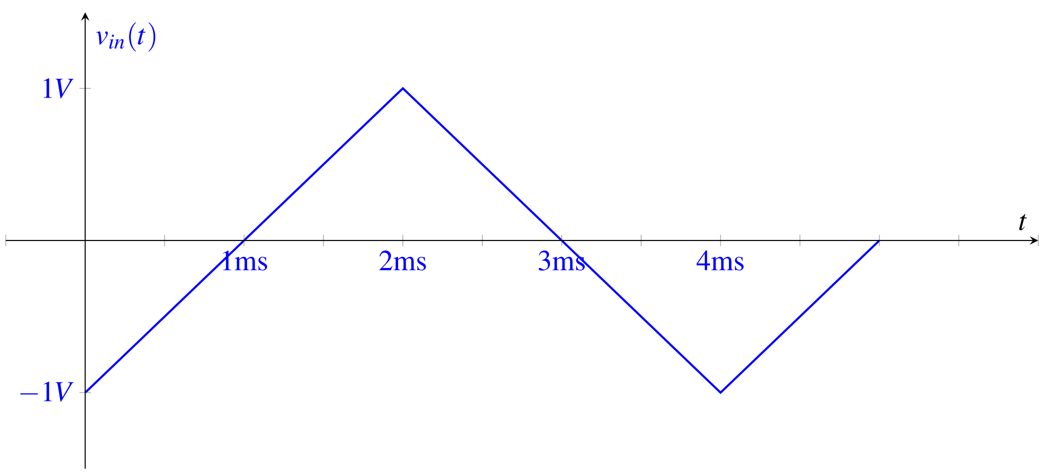


Note: The triangular block with the label "-5" in the figure above represents an amplifier with a factor of -5; In other words, it takes V_{out} as an input from the right side and outputs $-5V_{\text{out}}$ on the left side.

(e) Find the expression of v_{out} for the following circuit:



(f) Plot v_{out} vs. time for the following v_{in}. Assume $V_{DD} = 10\text{V}$, $V_{SS} = -10\text{V}$, $R_s = 100\Omega$, $R_f = 500\Omega$.



(g) What happens if R_f is changed to $R_f = 2000\Omega$. Plot v_{out} vs. time for the same v_{in}, where $V_{DD} = 10\text{V}$, $V_{SS} = -10\text{V}$, and $R_s = 100\Omega$.