EECS 16A Designing Information Devices and Systems I
Spring 2023 Discussion 9B

Note to students:

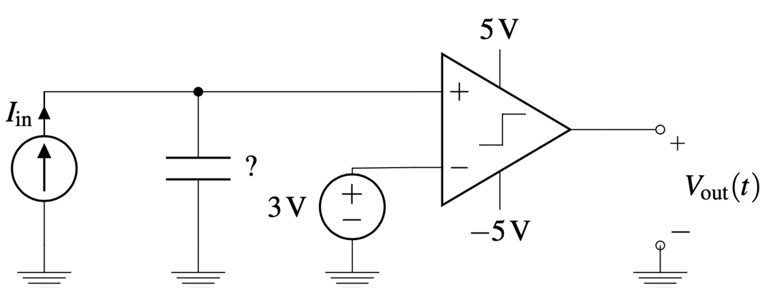
In this worksheet, we are using comparators (denoted by the little square wave within the op-amp symbol), which are distinct from op-amps that we will be covering in the coming weeks. While it is true op-amps can be used as comparators, this is not practical since comparators are faster than op amps, consume less power, and occupy smaller area. Op-amps are designed for signal amplifications whereas comparators are specifically dedicated to signal comparison (more on this later).

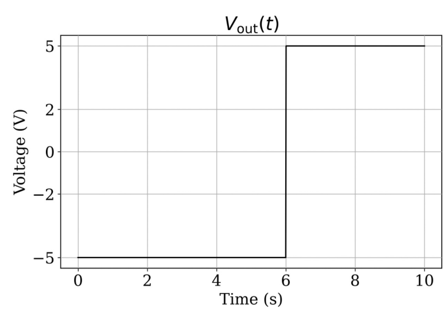
Here is the inherent logic of a comparator:

- If $V_+ > V_-$, then $V_{\text{out}} = V_{DD}$ (positive supply rail)
- If $V_+ < V_-$, then $V_{\text{out}} = V_{SS}$ (negative supply rail)

1. Comparators

We want to find the value of an unknown capacitor using the comparator outputs. For the circuit shown below (left), $I_{\text{in1}} = 1\mu$A , $I_{\text{in2}} = 3\mu$A, and $I_{\text{in3}} = 0.5\mu$A and the initial voltage across the capacitor is 0 when $t = 0$. The plot of $V_{\text{out}}(t)$ for time t from 0-10s is shown on the right. Note that $\mu = 10^{-6}$. What is the value of the capacitor for each value of I_{in}? *Note: the intial voltage across the capacitor at time t = 0 is 0V in all three cases.*



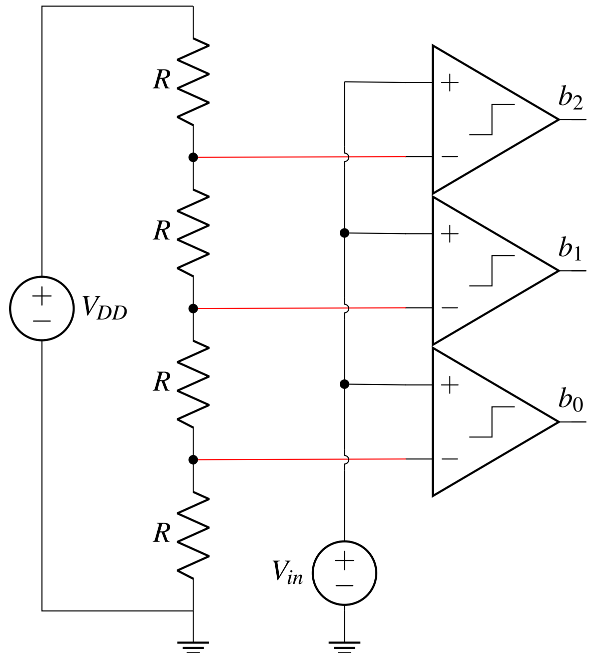


Solution/Answer: As shown in the left plot, the current source I_{in} is charging the unknown capacitor C over time, the charges on C at time t equals to the integral of current over time: $Q_C(t) = \int I_{in} dt = I_{in} t$. Therefore, we have $u_+(t) = V_C(t) = \frac{Q_C(t)}{C} = \frac{I_{in} t}{C}$. The turning point in the right graph is 6s, which means $V_C(6s) = \frac{I_{in} 6s}{C} = u_+ = u_- = 3V$.

I_{in1} $C = I_{in} \frac{6s}{3V} = 2\mu F$
I_{in2} $C = I_{in} \frac{6s}{3V} = 6\mu F$
I_{in3} $C = I_{in} \frac{6s}{3V} = 1\mu F$

2. Data Conversion Circuits

(a) The dual to DAC circuits are analog-to-digital converters, or ADC circuits. Here is an example of one, called a "Flash ADC," using resistors and comparators:



Note: The red wires in the diagram are regular wires, but have been colored to show that they do not touch the crossing black wires.

The resistor ladder gives us a set of reference voltages to compare against. We use a set of comparators to compare the input voltage V_{in} against these reference levels, and we get out a corresponding digital code b_0, b_1, and b_2.

Assume that $V_{DD} = 1\,\text{V}$, and that the comparators are connected to rails $V_{DD} = 1\,\text{V}$ and $V_{SS} = 0\,\text{V}$. If V_{in} is $0.3\,\text{V}$, **what are the outputs b_0, b_1, and b_2**?

Solution/Answer: The reference voltages for the comparators, from bottom to top, are $\frac{1}{4}V_{DD} = 0.25$ V, $\frac{1}{2}V_{DD} = 0.5$ V, and $\frac{3}{4}V_{DD} = 0.75$ V. Each comparator checks if V_{in} is greater than the reference voltage, outputing V_{DD} if it is greater and V_{SS} if not. We are given $V_{in} = 0.3$ V, so $b_0 = V_{DD} = 1\,\text{V}$, $b_1 = V_{SS} = 0\,\text{V}$, $b_2 = V_{SS} = 0\,\text{V}$.

If you left your answer in terms of 1s and 0s, i.e. $b_0 = 1, b_1 = 0, b_2 = 0$, that is valid too.