EECS 16B Designing Information Devices and Systems II
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Discussion 1A

1 KVL/KCL Review

Kirchhoff's Circuit Laws are two important laws used for analyzing circuits. Kirchhoff's Current Law (KCL) says that the sum of all currents entering a node must equal 0. For example, in Figure 1, the sum of all currents entering node 1 is $I_1 - I_2 - I_3 = 0$. Assuming that I_1 and I_3 are known, we can easily obtain a solvable equation for V_x by applying Ohm's law: $I_1 - \frac{V_x}{R_1} - I_3 = 0$.

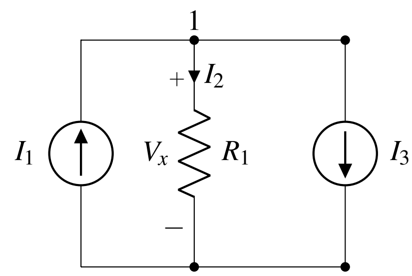

Figure 1: KCL Circuit

Kirchhoff's Voltage Law (KVL) states that the sum of all voltages in a circuit loop must equal 0. To apply KVL to the circuit shown in Figure 2, we can add up voltages in the loop in the counterclockwise direction, which yields $-V_1 + V_x + V_y = 0$. Using the relationships $V_x = i \cdot R_1$ and $i = I_1$, we can solve for all unknowns in this circuit. You can use these two laws to solve any circuit that is planar and linear.

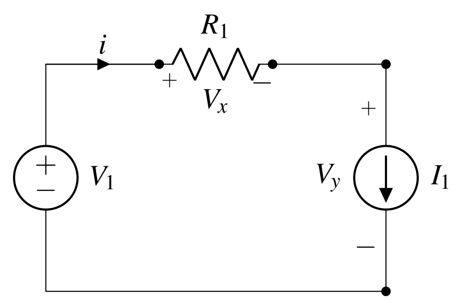

Figure 2: KVL Circuit

If you would like to review these concepts more in-depth, you can check out the EE16A spring 2018 course notes

2 Op-amp Review

Figure 3 shows the equivalent model of an op-amp. It is important to note that this is the general model of an op-amp, so our op-amp golden rules cannot be applied to this unless certain conditions are met.

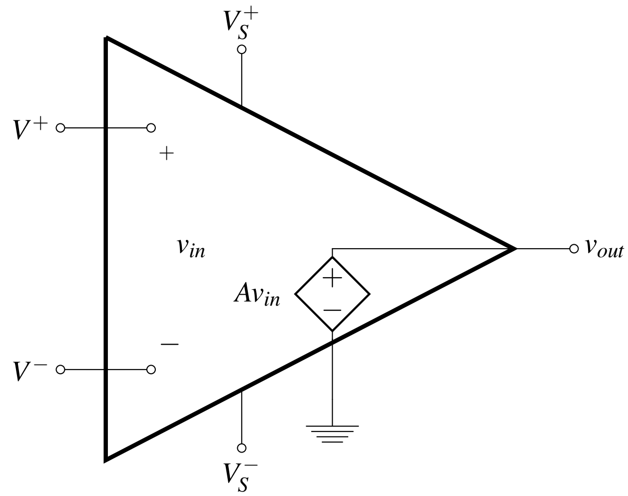

Figure 3: General Op-Amp Model

Conditions Required for the Golden Rules:

(a) $R_{in} \to \infty$

(b) $R_{out} \to 0$

(c) $A \to \infty$

(d) The op-amp must be operated in negative feedback.

When conditions 1-3 are met, the op-amp is considered ideal. Figure 4 shows an ideal op-amp in negative feedback, which can be analyzed using the Golden Rules.

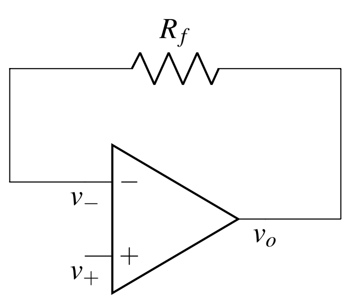

Figure 4: Ideal Op-Amp in Negative Feedback

Golden Rules of ideal op-amps in negative feedback:

(a) No current can flow into the input terminals ($I_- = 0$ and $I_+ = 0$).

(b) The $(+)$ and $(-)$ terminals are at the same voltage ($V_+ = V_-$).

If you would like to review these concepts more in-depth, you can check out op-amp introduction and op-amp negative feedback from the EE16A spring 2018 course notes.

1. KVL/KCL Review

Use Kirchhoff's Laws on the circuit below to find V_x in terms of V_{in}, R_1, R_2, R_3.

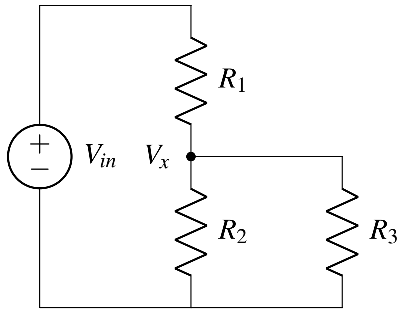

Figure 5: Example Circuit

(a) What is V_x?

Answer:

Applying KCL to the node at V_x, we get

$$\frac{V_x - V_{in}}{R_1} + \frac{V_x}{R_2} + \frac{V_x}{R_3} = 0$$

Solving this equation for V_x yields

$$V_x = V_{in} \frac{R_2 R_3}{R_1 R_2 + R_1 R_3 + R_2 R_3}$$

(b) As $R_3 \to \infty$, what is V_x? What is the name we used for this type of circuit?

Answer:

As $R_3 \to \infty$, the $R_1 R_2$ term on the denominator will become insignificant, simplifying our expression.

$$\begin{aligned} \lim_{R_3 \to \infty} V_x &= \lim_{R_3 \to \infty} V \frac{R_2 R_3}{R_1 R_2 + R_1 R_3 + R_2 R_3} \\ &= V_{in} \frac{R_2 R_3}{R_1 R_3 + R_2 R_3} \\ &= V_{in} \frac{(R_2) R_3}{(R_1 + R_2) R_3} \\ &= V_{in} \frac{R_2}{R_1 + R_2} \end{aligned}$$

When $R_3 \to \infty$, it effectively becomes an open wire, which makes the rest of the circuit a voltage divider, or resistive divider.

2. Op-Amp Summer

Consider the following circuit:

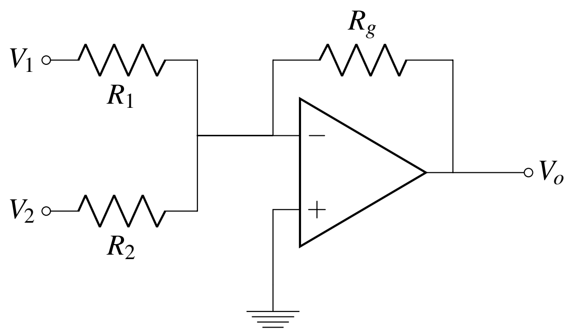

Figure 6: Op-amp Summer

What is the output V_o in terms of V_1 and V_2? You may assume that R_1, R_2, and R_g are known.

Answer:

$$i_- = \frac{V_1}{R_1} + \frac{V_2}{R_2}$$
$$V_o = -R_g i_-$$
$$V_o = -\left(\frac{R_g}{R_1} \cdot V_1 + \frac{R_g}{R_2} \cdot V_2\right)$$