Introduction to Measurements Systems
LA-CoNGA physics - 2022

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February 2, 2022

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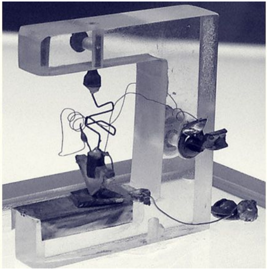
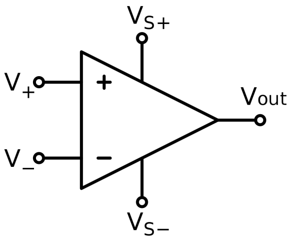
Introduction

- Amplifying a signal (voltage or current) is one of the fundamental tasks made in measurement systems.
- Amplifying means that we produce an output signal with more power than the input signals.
- First application of transistors, in fact, was to amplify sound.

- The operational amplifier (op-amp) is one of the basic building blocks of linear design.
- In its basic form it consists of two input terminals, one of which inverts the phase of the signal, the other preserves the phase, and an output terminal.
- The most basic model of the ideal voltage feedback op amp has the following characteristics:
  - Infinite input impedance
  - Infinite bandwidth
  - Infinite voltage gain
  - Zero output impedance
  - Zero power consumption

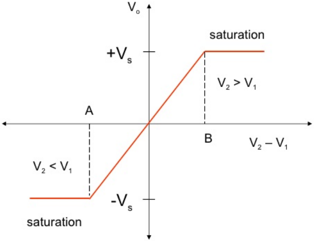
- The circuit symbol for the op-amp is shown, all of the voltages for the op-amp are referenced to ground



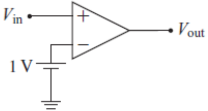
$$V_{out} = A_{OL}(V_+ - V_-)$$

- The output voltage is proportional to the difference between the inverting and non-inverting input voltages

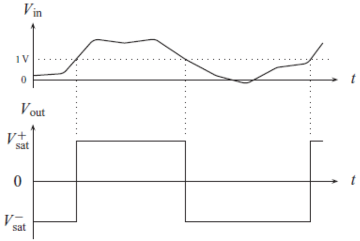
- Typically, A_{OL} is very large ($\approx$ 200000 for $\mu A741$)
- The output voltage V_{out} can only be within a range set by two saturation voltages
$$V_{sat}^{-} \leq V_{out} \leq V_{sat}^{+}$$
- where $V_{sat}^{+} \approx V_{s+} - 1V$ and $V_{sat}^{-} \approx V_{s-} + 1V$
- It means that any small difference between the op-amp inputs will cause the output to saturate



- This circuit compares the voltage at the two inputs and gives a positive or negative output depending on which input is larger.



- The relationship between the input and output signals is clearly not proportional (i.e., the operation is non-linear).

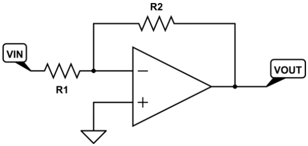


- In linear applications (i.e. voltage output is proportional to inputs) the op-amp circuits can be analyzed by applying **the golden rules**

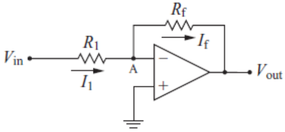
1. The output will do whatever is necessary to make the voltage difference between the inputs zero.

2. No current flows into the inputs.

- These circuits are characterized by a single feedback connection from the output to the inverting input



- Let's apply the golden rules



- Ohm's law tell us

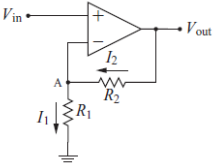
$$V_{in} - V_A = I_1 R_1$$

$$V_A - V_{out} = I_f R_f$$

- But $V_A = 0$ (rule 1) and $I_1 = I_f$ (rule 2) so:

$$V_{out} = -\frac{R_2}{R_1} V_{in}$$

- By rule 1, the voltage at point A is equal to the input voltage, $V_A = Vin$, By rule 2 $I_2 = I_1$



- Ohm's law tell us

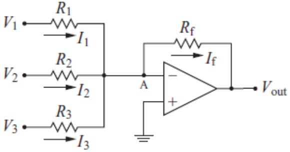
$$I_1 = \frac{V_{in}}{R_1}$$

$$V_{out} - V_{in} = I_2 R_2$$

$$V_{out} = \left(1 + \frac{R_f}{R_1}\right) V_{in}$$

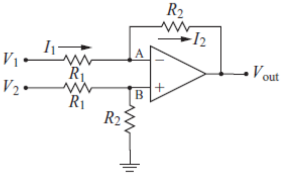
Applications

- Summing amplifier



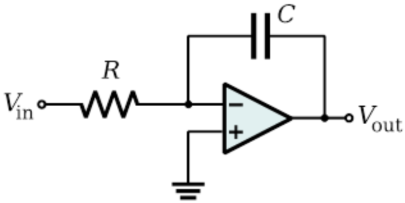
$$V_{out} = -\left(\frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2 + \frac{R_f}{R_3}V_3\right)$$

- The differential amplifier



$$V_{out} = \frac{R_2}{R_1}(V_2 - V_1)$$

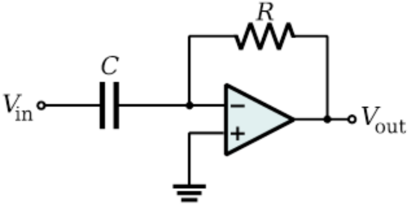
- An integrator is a circuit which has an output voltage that is proportional to the time integral of its input voltage.



- The output of this circuit is

$$V_{out} = -\int_0^t \frac{V_{in}}{RC} + V_o$$

- An differentiator is a circuit which has an output voltage that is proportional to the time derivate of its input voltage.



- The output of this circuit is

$$V_{out} = -RC\frac{dV_{in}}{dt}$$

Exercises

- Simulate an integrator circuit with the input resistor $R = 2.5K\Omega$ and the feedback capacitor $C = 0.1\mu F$. The input voltage V_{in} is a $-1V$ to $+1V$ square wave with a $1ms$ period.
- Simulate a differentiator circuit with the same specifications
- Design a circuit that converts a sine wave $5V_{pp}$ and $1KHz$ to a square wave

Homework: Active filters, op-amps can be used to improve frequency filters performance, investigate and describe this application with simulations