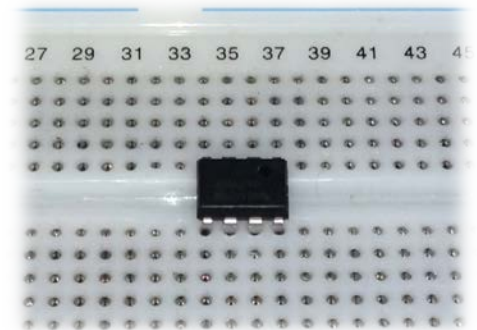




ELECTRONIC DEVICES

Assist. prof. Laura-Nicoleta IVANCIU, Ph.D.

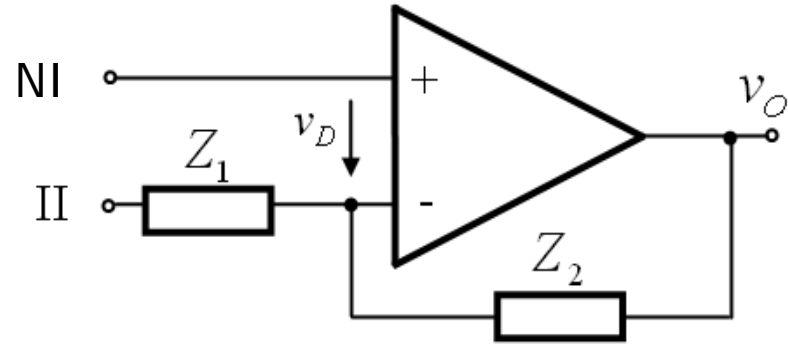
C9 – Summing and differential amplifiers with OpAmp



Contents

- Summing amplifiers with OpAmp
 - Inverting summing amplifier
 - Non-inverting summing amplifier
- Differential amplifiers with OpAmp
- Recap – circuits with OpAmp

Types of amplifiers with OpAmp



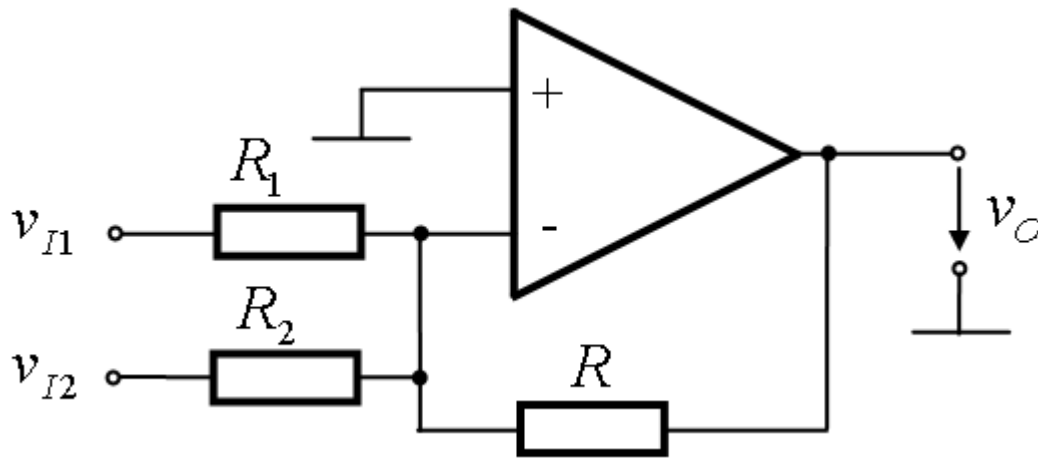
NI	II	Amplifier
v_1	ground	non-inverting
ground	v_1	inverting
v_{I1}	v_{I2}	differential
v_{I1}, v_{I2}	ground	summing, non-inverting
ground	v_{I1}, v_{I2}	summing, inverting

C8

C8

C9

➤ Inverting summing amplifier



How can we compute v_O ?

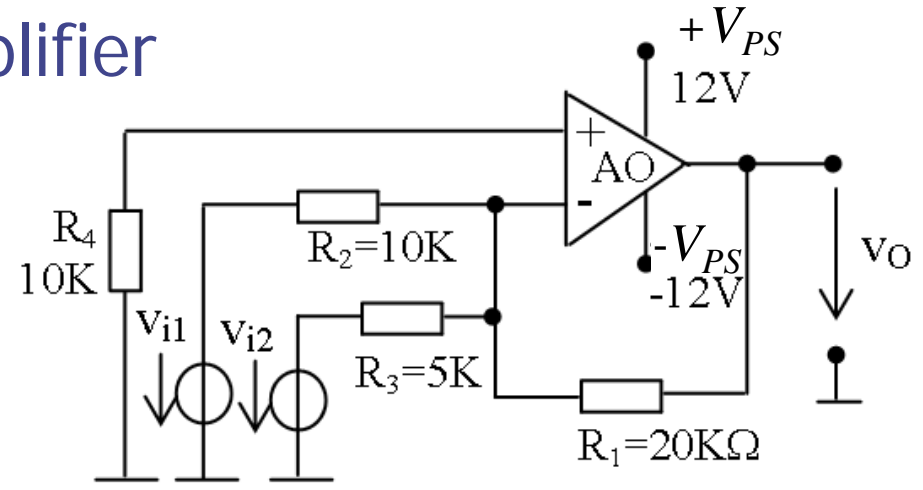
$$v_O = -\left(\frac{R}{R_1}v_{I1} + \frac{R}{R_2}v_{I2}\right)$$

Relationship between resistors to obtain the average of input voltages:

$$R_1 = R_2 = 2R$$

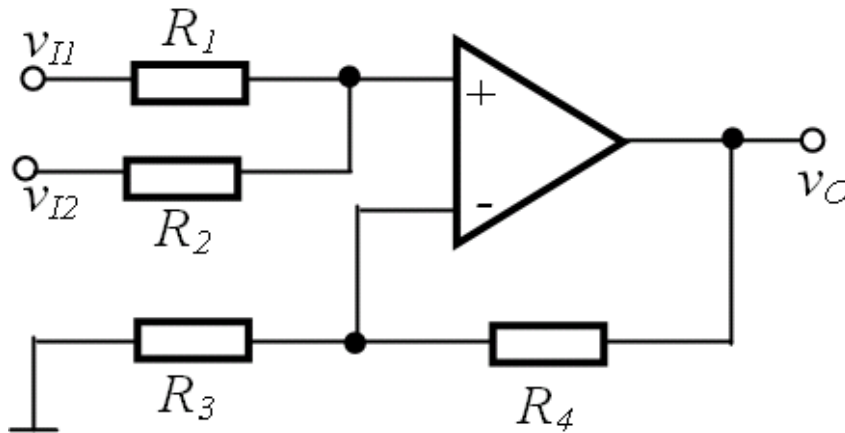
➤ Inverting summing amplifier

Example



- a) $v_O(v_{i1}, v_{i2})$ assuming op amp in the active region. What is the application of the circuit?
- b) Considering $v_{i1} = 2\text{ V}$, plot the VTC $v_O(v_{i2})$ for $v_{i2} \in [-5\text{ V}; 5\text{ V}]$. What is the v_{i2} range, so that the amplifier works in its active region?
- c) Plot $v_{i1}(t)$, $v_{i2}(t)$ and $v_O(t)$ for $v_{i1}(t) = 1\sin\omega t$ [V], $v_{i2}(t) = 0.5\sin\omega t$ [V].
- d) Resize R_1, R_2, R_3, R_4 so that $v_O = -(v_{i1} + v_{i2})$.
- e) Modify the circuit, in order to obtain a non-inverting summing circuit, with $v_O = v_{i1} + v_{i2}$.

➤ Non-inverting summing amplifier



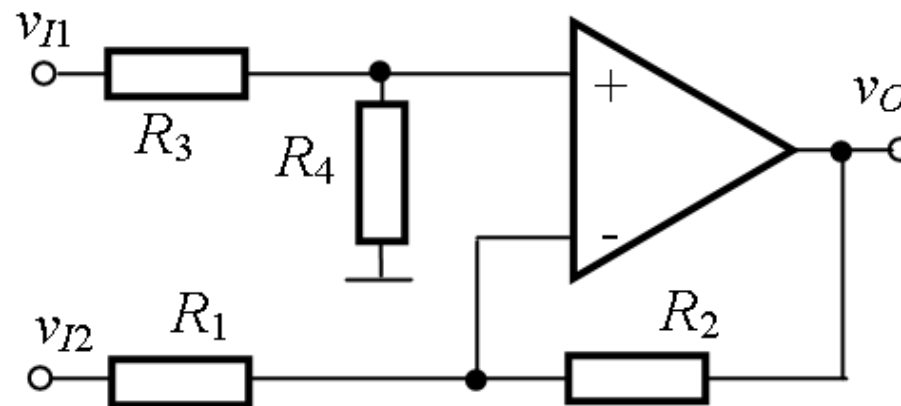
$$v_O = \left(1 + \frac{R_4}{R_3}\right) \left(\frac{R_2}{R_1 + R_2} v_{I1} + \frac{R_1}{R_1 + R_2} v_{I2} \right)$$

Relationship between resistors to have $v_O = v_{I1} + v_{I2}$?

$$R_1 = R_2 \quad \text{and} \quad R_3 = R_4$$

Usually $R_1 = R_2 = R_3 = R_4$

➤ Differential amplifier

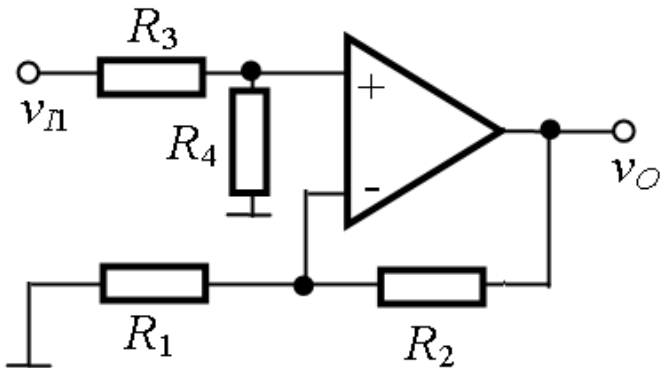
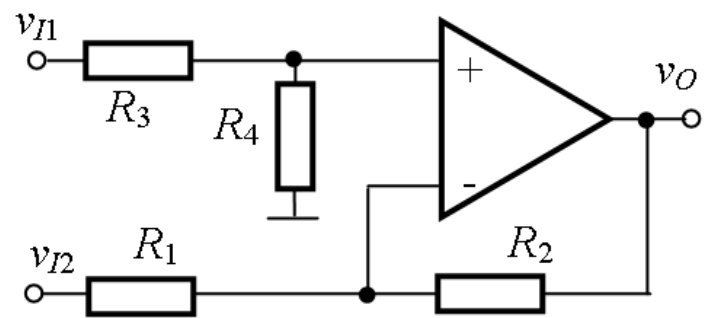


How can we compute v_O ?

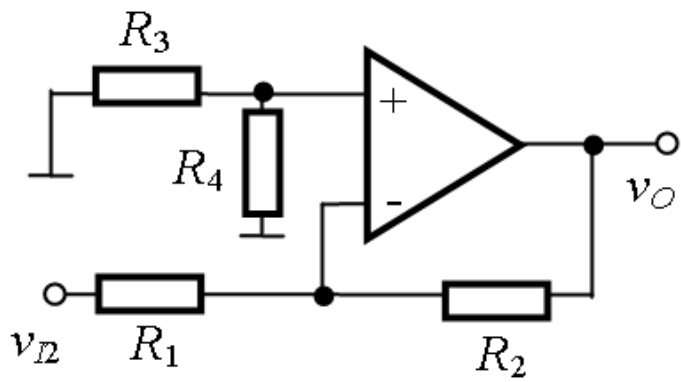
$$v_O = \frac{R_4}{R_3 + R_4} \left(1 + \frac{R_2}{R_1} \right) v_{I1} - \frac{R_2}{R_1} v_{I2}$$

➤ Differential amplifier

Superposition method



$$v_{O1} = \frac{R_4}{R_3 + R_4} \left(1 + \frac{R_2}{R_1} \right) v_{I1}$$

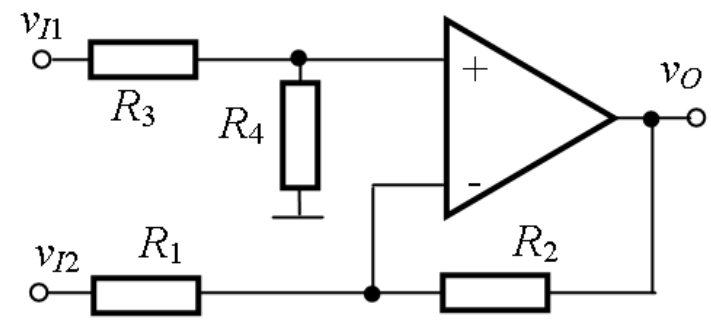


$$v_{O2} = -\frac{R_2}{R_1} v_{I2}$$

$$v_O = v_{O1} + v_{O2} = \frac{R_4}{R_3 + R_4} \left(1 + \frac{R_2}{R_1} \right) v_{I1} - \frac{R_2}{R_1} v_{I2}$$

➤ Differential amplifier

$$v_O = \frac{R_4}{R_3 + R_4} \left(1 + \frac{R_2}{R_1} \right) v_{I1} - \frac{R_2}{R_1} v_{I2}$$



If the goal is to amplify $(v_{I1} - v_{I2})$:

$$\frac{R_4}{R_3 + R_4} \left(1 + \frac{R_2}{R_1} \right) = \frac{R_2}{R_1}$$

$$\frac{R_1}{R_2} = \frac{R_3}{R_4}$$

$$v_O = \frac{R_2}{R_1} (v_{I1} - v_{I2})$$

For $v_{I1} = v_{I2}$, $v_O = 0$.

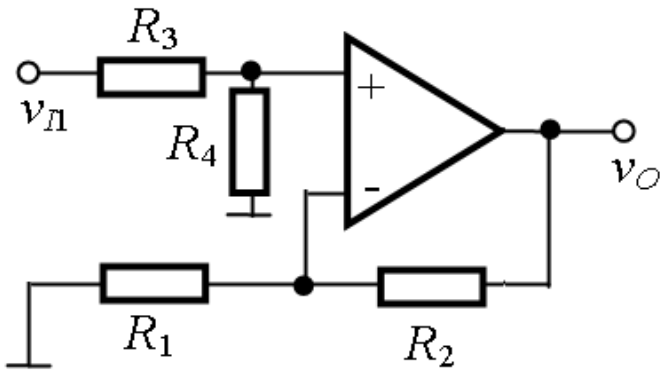
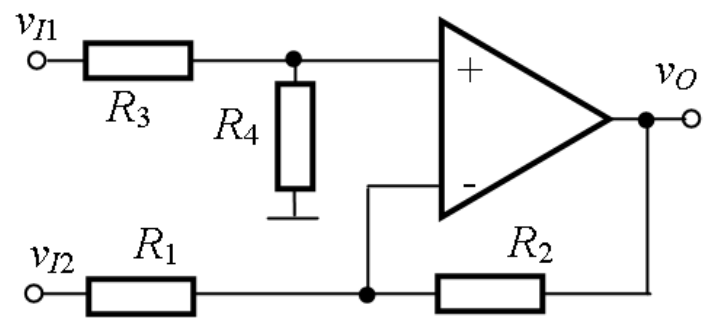
The circuit **amplifies** the **difference** between the input voltages and **rejects** common mode signals.

$$\begin{aligned} v_{I1} &= v_1 + v_{noise} \\ v_{I2} &= v_2 + v_{noise} \end{aligned} \quad v_O = A_v (v_1 + v_{noise} - v_2 - v_{noise}) = A_v (v_1 - v_2)$$

In practical situations: $R_1 = R_3$ and $R_2 = R_4$

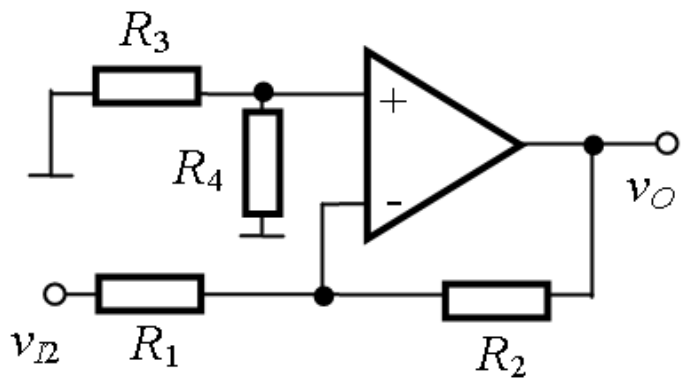
➤ Differential amplifier

Superposition method



Input resistance, seen by v_{I1}

$$R_{I1} = R_3 + R_4$$



Input resistance, seen by v_{I2}

$$R_{I2} = R_1$$

➤ Differential amplifier

Example

A sensor provides a variable signal, v_i , with a dc component, V_i .

It is necessary to amplify the variable signal, that carries information, 10 times.

Design a differential amplifier for this requirement.

➤ Differential amplifier

Example

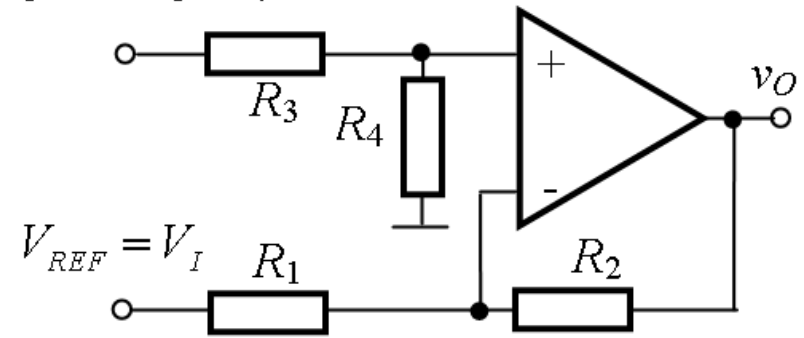
$$v_o(t) = \frac{R_4}{R_3 + R_4} \left(1 + \frac{R_2}{R_1} \right) v_I(t) - \frac{R_2}{R_1} V_{REF}$$

$$v_o(t) = \frac{R_4}{R_3 + R_4} \left(1 + \frac{R_2}{R_1} \right) (V_I + v_i(t)) - \frac{R_2}{R_1} V_I$$

$$\frac{R_4}{R_3 + R_4} \left(1 + \frac{R_2}{R_1} \right) - \frac{R_2}{R_1} = 0 \quad \frac{R_4}{R_3 + R_4} \left(1 + \frac{R_2}{R_1} \right) = 10$$

$$\frac{R_1}{R_2} = \frac{R_3}{R_4} \quad \frac{R_1}{R_2} = \frac{R_3}{R_4} = \frac{1}{10}$$

$$v_I(t) = V_I + v_i(t)$$



$$R_1 = R_3 = 2,5\text{k}\Omega$$

$$R_2 = R_4 = 25\text{k}\Omega$$

$$v_o(t) = 10v_i(t)$$

➤ Differential amplifier

Standard instrumentation amplifier

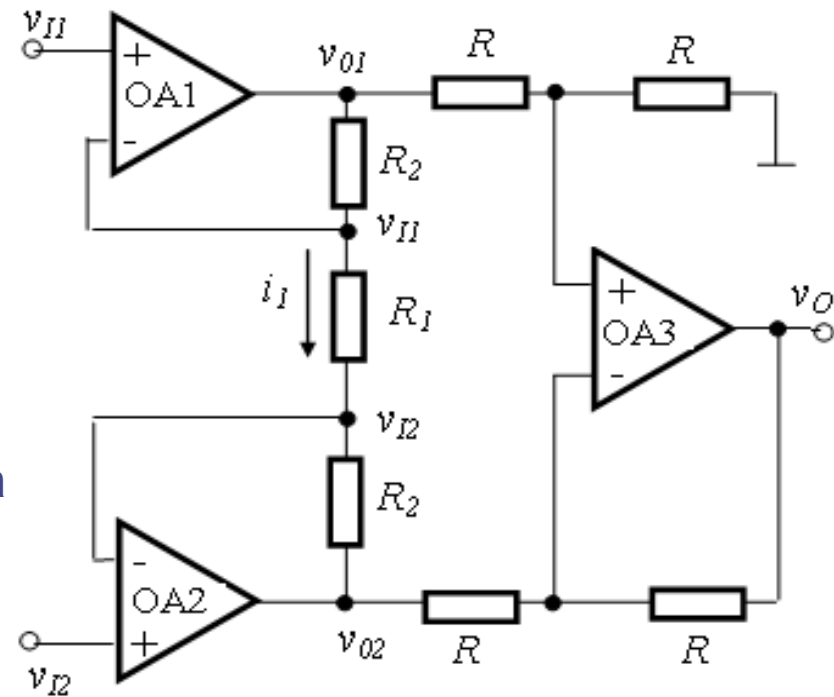
- high R_i
- very good common mode rejection ratio

OA1 and OA2:

- high input resistance
- set the gain

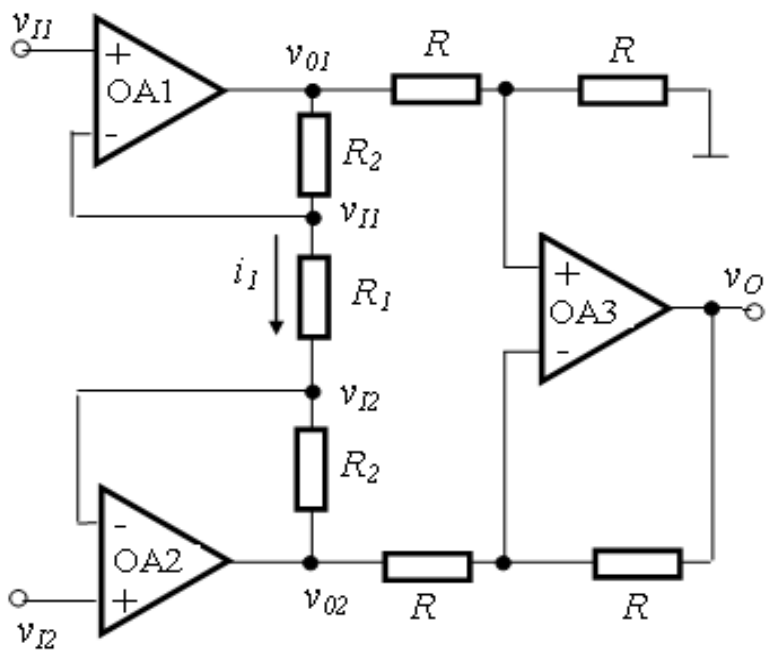
OA3:

- gain = 1
- conversion from two voltages (v_{O1} and v_{O2}) to a single voltage (v_O)
- additional rejection of the common mode



➤ Differential amplifier

Standard instrumentation amplifier



$$v_{O1} = \left(1 + \frac{R_2}{R_1}\right)v_{I1} - \frac{R_2}{R_1}v_{I2}$$

$$v_{O2} = \left(1 + \frac{R_2}{R_1}\right)v_{I2} - \frac{R_2}{R_1}v_{I1}$$

$$v_O = \frac{R}{R}(v_{O1} - v_{O2})$$

$$v_O = \left(1 + \frac{2R_2}{R_1}\right)(v_{I1} - v_{I2})$$

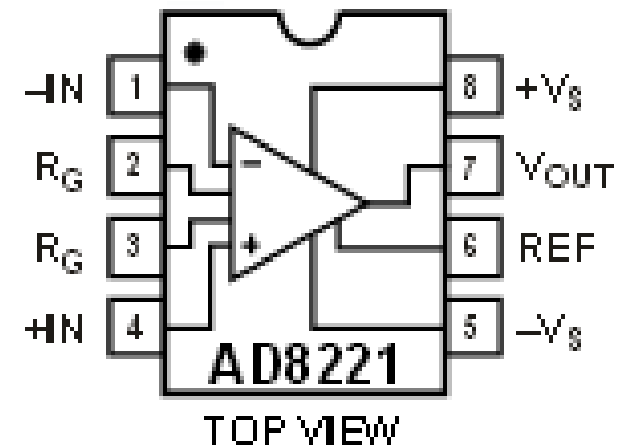
➤ Differential amplifier

Integrated precision differential amplifiers

- **AD8221** Analog Devices
Precision Instrumentation Amplifier

$$A_v = 1 + (49.4 \text{ k}\Omega/R_G)$$

- **MAX4194, MAX4195, MAX4196, MAX4197**
Micropower, Single-Supply, Rail-to-Rail, Precision Instrumentation
Amplifiers Maxim Integrated
- **LT1167** Linear Technology



Common uses of instrumentation amplifiers: sensor readings for medical and industrial applications. **Examples?**

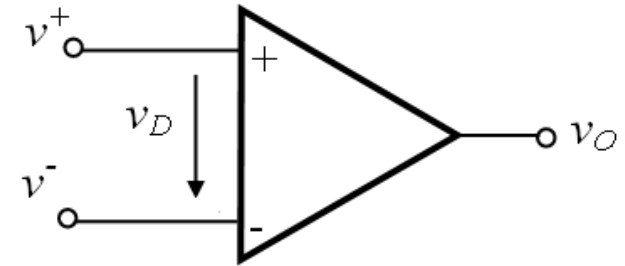
Recap – circuits with OpAmp

Given a circuit with OpAmp, how can we tell whether the circuit is:

- inverting or non-inverting?
- a simple comparator, a hysteresis comparator, or an amplifier?

What parameters do we compute, for each of the above? What can we tell about the output voltage?

Recap – circuits with OpAmp



Type of feedback	v_i goes to	Application	We compute	v_O
No feedback	NI	Simple comparator, non-inverting	V_{Th}	$v_O \in \{V_{OL} ; V_{OH}\}$
	II	Simple comparator, inverting		
Positive feedback	NI	Hysteresis comparator, non-inverting	V_{ThL} V_{ThH}	$v_O \in \{V_{OL} ; V_{OH}\}$
	II	Hysteresis comparator, inverting		
Negative feedback	NI	Amplifier, non-inverting	A_v	$v_O \in (V_{OL} ; V_{OH})$
	II	Amplifier, inverting		

Summary

Today's menu consisted of a fine selection of OpAmp circuits, such as:

- Summing amplifiers with OpAmp
 - Inverting summing amplifier
 - Non-inverting summing amplifier
- Differential amplifiers with OpAmp
- Recap – circuits with OpAmp

Next week: Applications with OpAmp

To do: Homework 7