ELECTRONIC DEVICES

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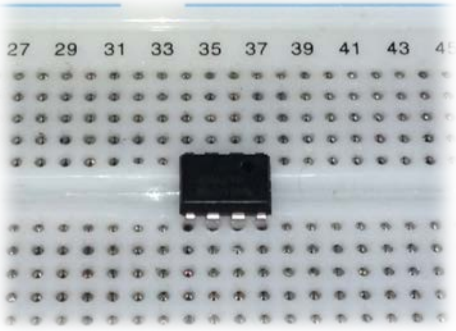
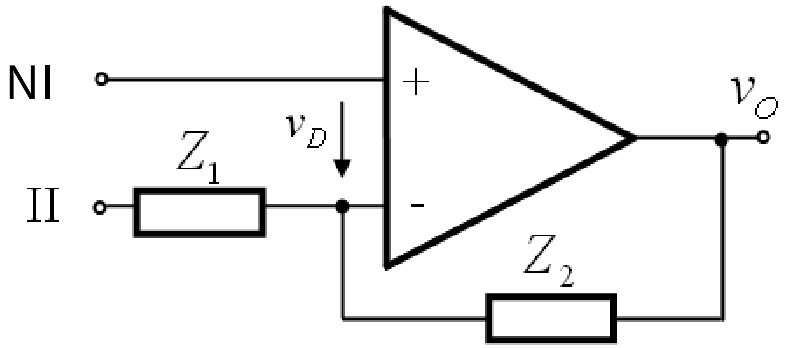
C9 – Summing and differential amplifiers with OpAmp



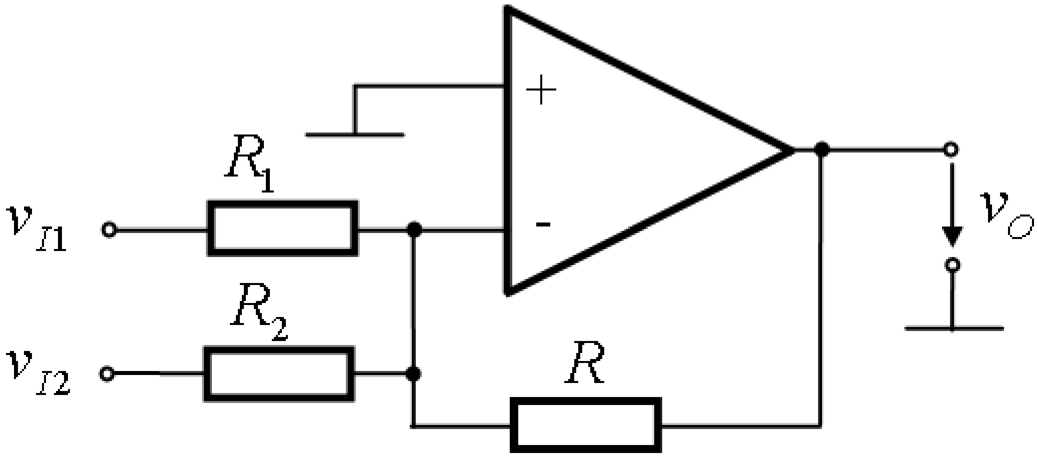
Contents

Types of amplifiers with OpAmp



NI	II	Amplifier	
v_I	ground	non-inverting	C8
ground	v_I	inverting	C8
v_{I1}	v_{I2}	differential	
v_{I1}, v_{I2}	ground	summing, non-inverting	C9
ground	v_{I1}, v_{I2}	summing, inverting	

➢ Inverting summing amplifier



How can we compute v_O?

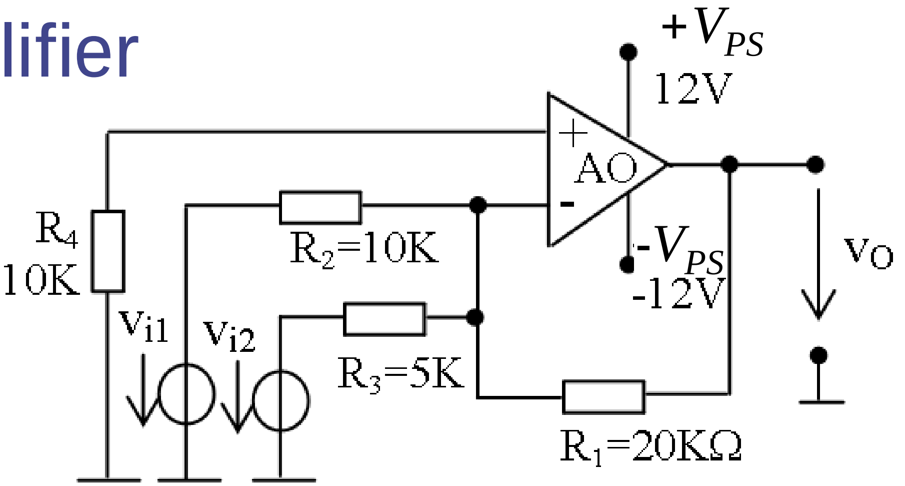
$$v_O = -\left(\frac{R}{R_1}v_{I1} + \frac{R}{R_2}v_{I2}\right)$$

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 $v_{I1} = 2$ 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?

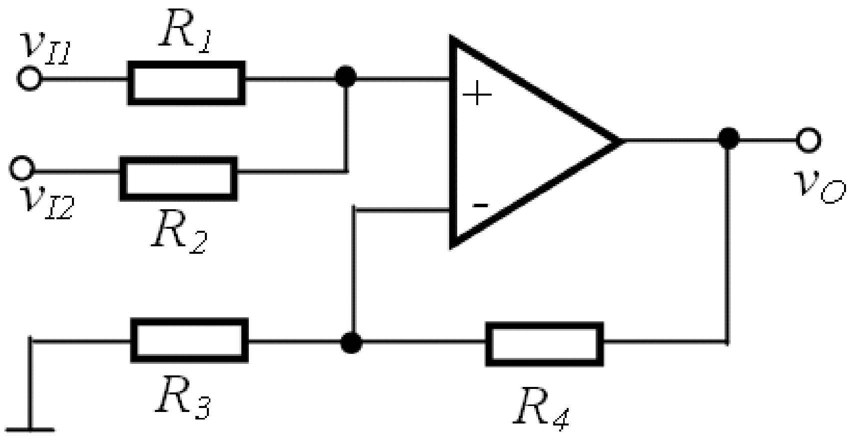
c) Plot $v_{I1}(t)$, $v_{I2}(t)$ and $v_O(t)$ for $v_{I1}(t) = 1\sin\omega t$ [V], $v_{I2}(t) = 0.5\sin\omega t$ [V].

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 $v_O = v_{I1} + v_{I2}$.

Summing amplifiers

Non-inverting summing amplifier



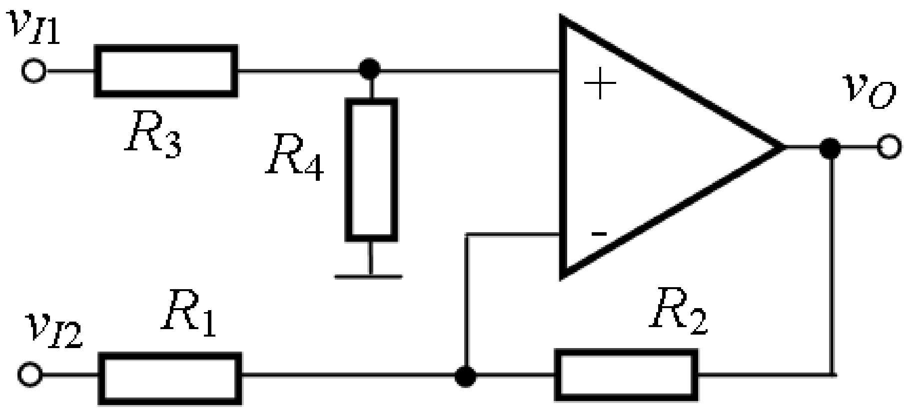
$$v_O = \left(1 + \frac{R_4}{R_3}\right)\left(\frac{R_2}{R_1 + R_2} v_{I1} + \frac{R_1}{R_1 + R_2} v_{I2}\right)$$

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

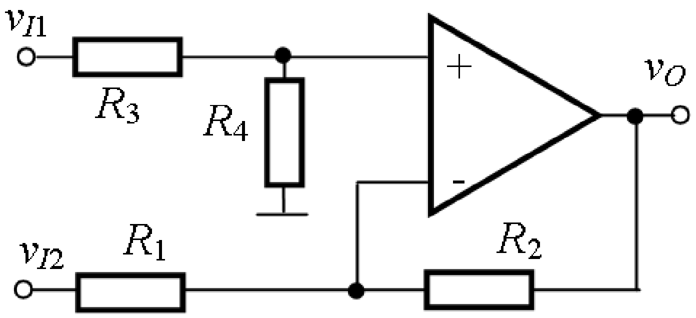


How can we compute v_O?

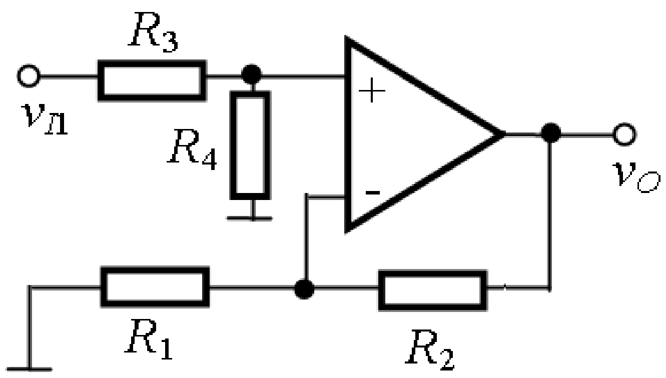
$$v_O = \frac{R_4}{R_3 + R_4}\left(1 + \frac{R_2}{R_1}\right)v_{I1} - \frac{R_2}{R_1}v_{I2}$$

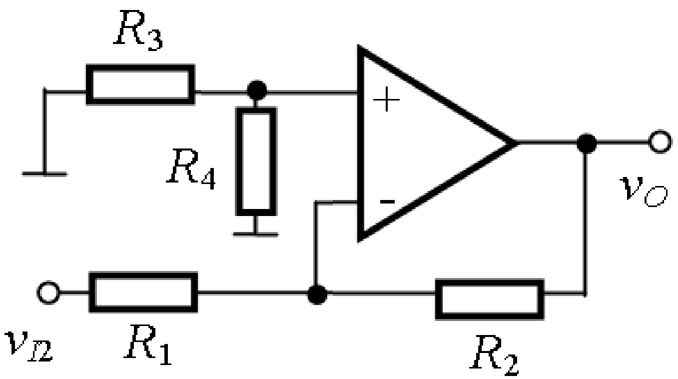
Differential amplifiers

- ## Differential amplifier



Superposition method



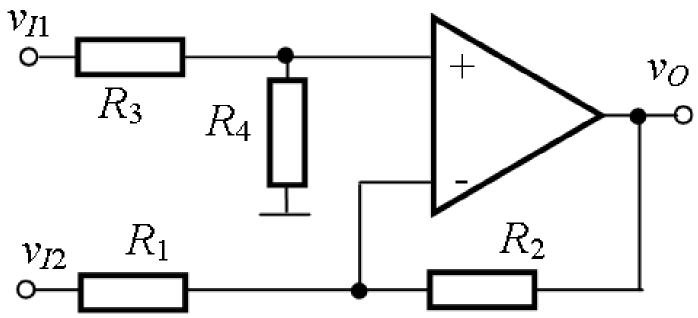


$$v_{O1} = \frac{R_4}{R_3 + R_4}\left(1 + \frac{R_2}{R_1}\right) v_{I1}$$

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

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

Differential amplifiers



➢ Differential amplifier

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

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

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

$$\boxed{\frac{R_1}{R_2} = \frac{R_3}{R_4}} \qquad \boxed{v_O = \frac{R_2}{R_1}(v_{I1} - v_{I2})}$$

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

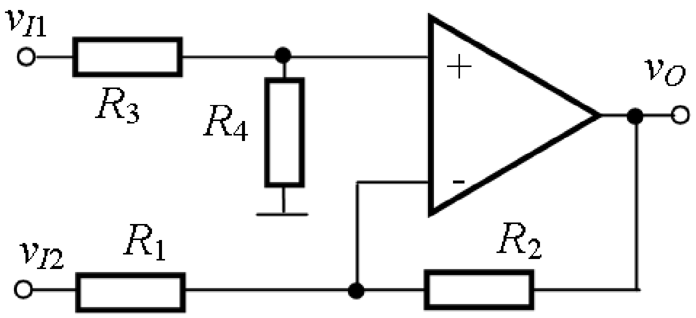
The circuit **amplifies** the difference between the input voltages and **rejects** common mode signals.

$$v_{I1} = v_1 + v_{noise}$$
$$v_{I2} = v_2 + v_{noise}$$

$$v_O = A_v(v_1 + v_{noise} - v_2 - v_{noise}) = A_v(v_1 - v_2)$$

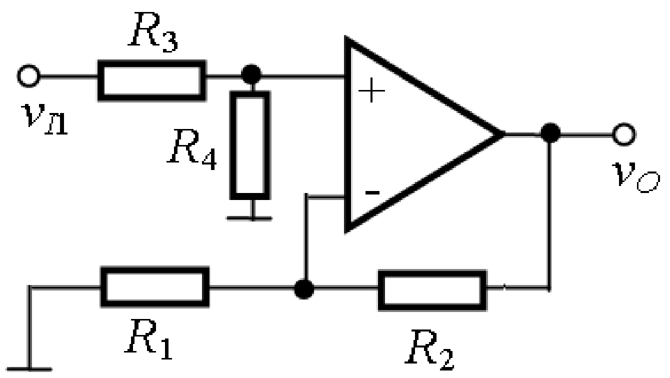
In practical situations: $R_1 = R_3$ and $R_2 = R_4$

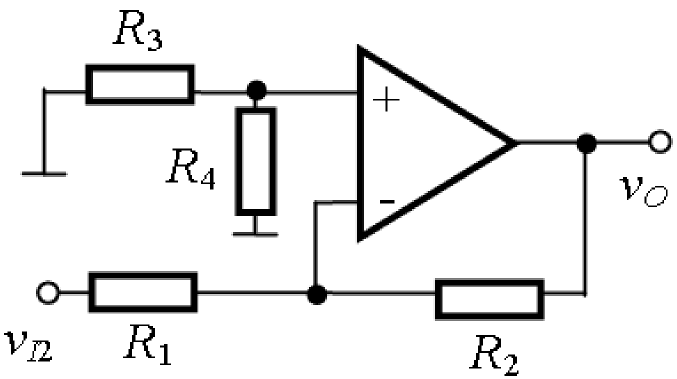
Differential amplifiers



- 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

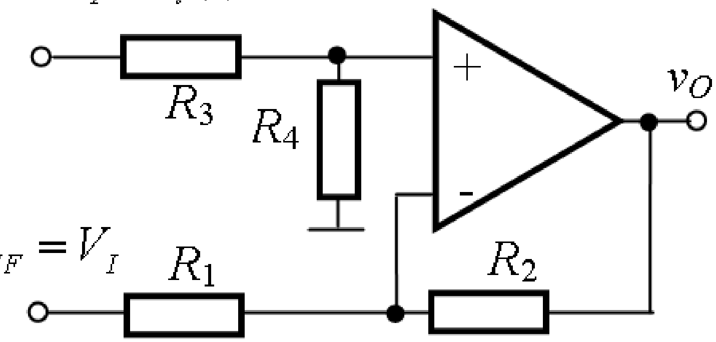
A sensor provides a variable signal, v_i, with a dc component, V_I.

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

Design a differential amplifier for this requirement.

Differential amplifiers

➢ Differential amplifier



Example

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

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

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

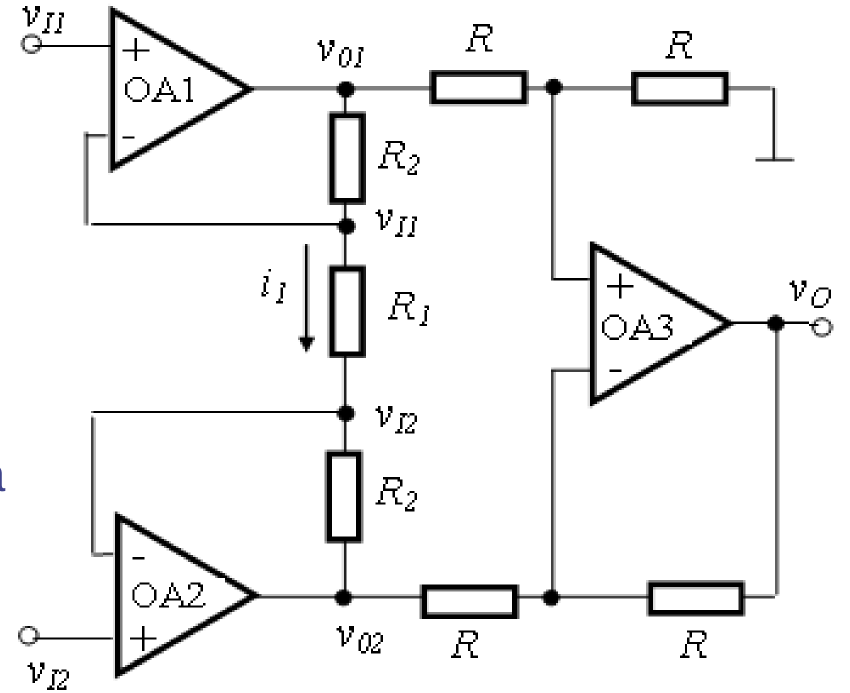
$$\frac{R_1}{R_2} = \frac{R_3}{R_4} \qquad \frac{R_1}{R_2} = \frac{R_3}{R_4} = \frac{1}{10}$$

$$\boxed{R_1 = R_3 = 2{,}5\text{k}\Omega}$$
$$\boxed{R_2 = R_4 = 25\text{k}\Omega}$$
$$\boxed{v_o(t) = 10 v_i(t)}$$

Differential amplifier

Standard instrumentation amplifier

- high R_i
- very good common mode rejection ratio



OA1 and OA2:

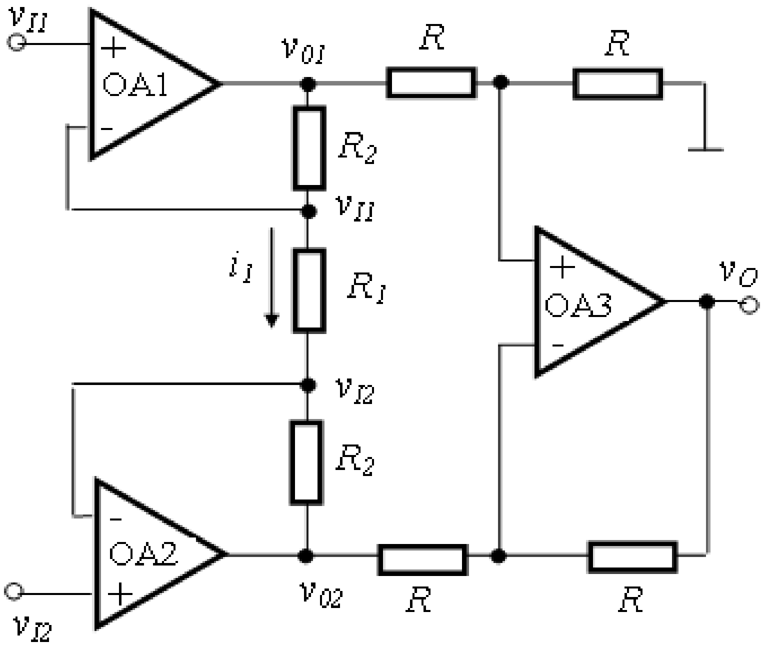
- high input resistance
- set the gain

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



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

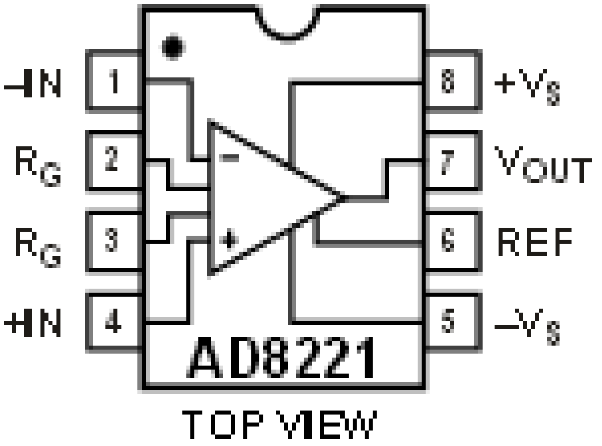
$$v_{O2} = \left(1 + \frac{R_2}{R_1}\right) v_{I2} - \frac{R_2}{R_1} v_{I1}$$

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

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

Differential amplifier

Integrated precision differential amplifiers



- **AD8221** Analog Devices

Precision Instrumentation Amplifier

$$Av = 1 + (49.4\ k\Omega/R_G)$$

- **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

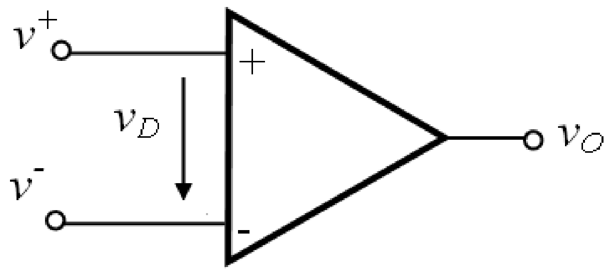
Given a circuit with OpAmp, how can we tell whether the circuit is:

- 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

Recap – circuits with OpAmp



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