ELECTRONIC DEVICES

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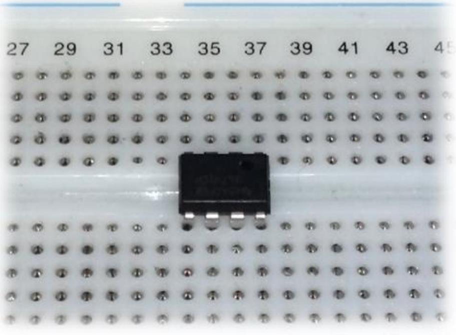
C8 – Electronic amplifiers. Amplifiers with OpAmp.

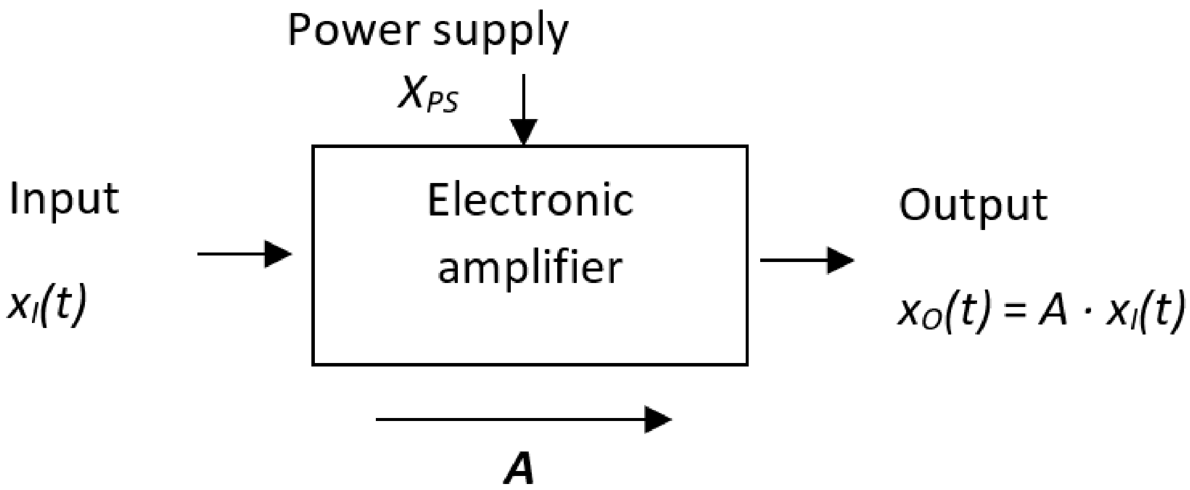


Contents

- Electronic amplifiers
    - Types of supply
    - Power transfer and power balance
    - Types of amplifiers
    - Parameters
    - Modeling the voltage amplifier
- Amplifiers with OpAmp
    - Non-inverting amplifier
    - Inverting amplifier

Electronic amplifiers

Amplifier = active three-port network that delivers an output signal $x_o(t)$ (voltage or current) with the same shape as the input signal $x_i(t)$ and can provide more power, on an adequate load.



$$A = \frac{x_O(t)}{x_I(t)}$$

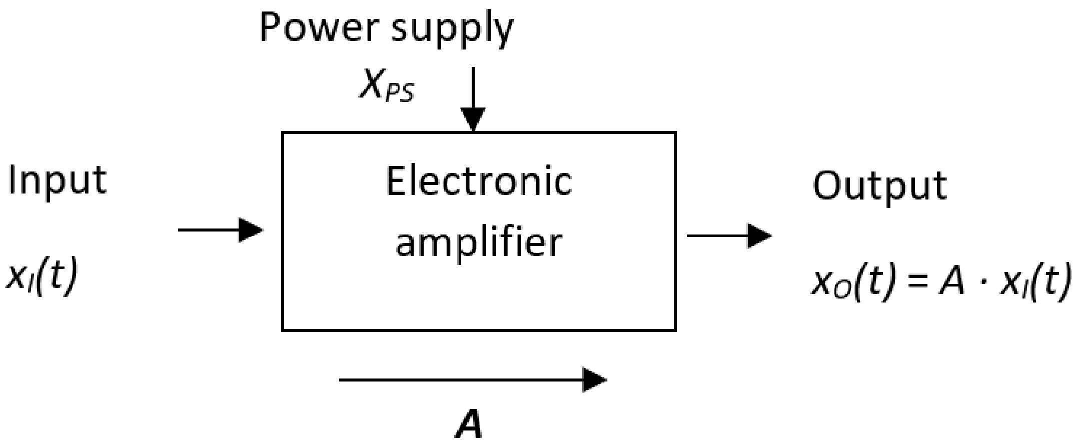
Linear circuit: x_0 proportional with x_i

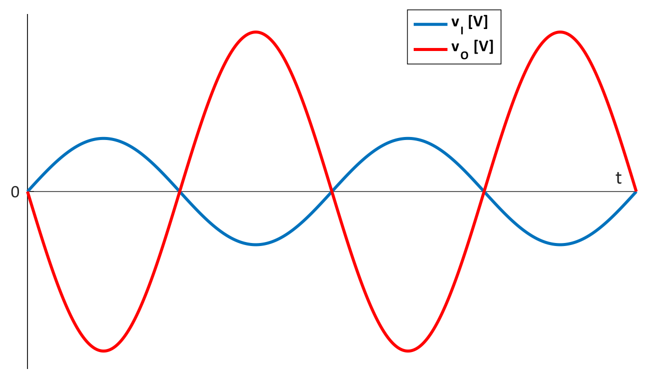
A – gain (amplification)

$A < 0$ inverting

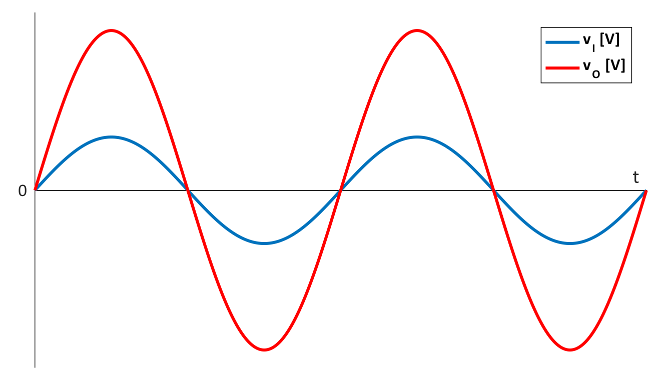
$A > 0$ non-inverting

Electronic amplifiers





Inverting amplifier (A < 0)



Non-inverting amplifier (A > 0)

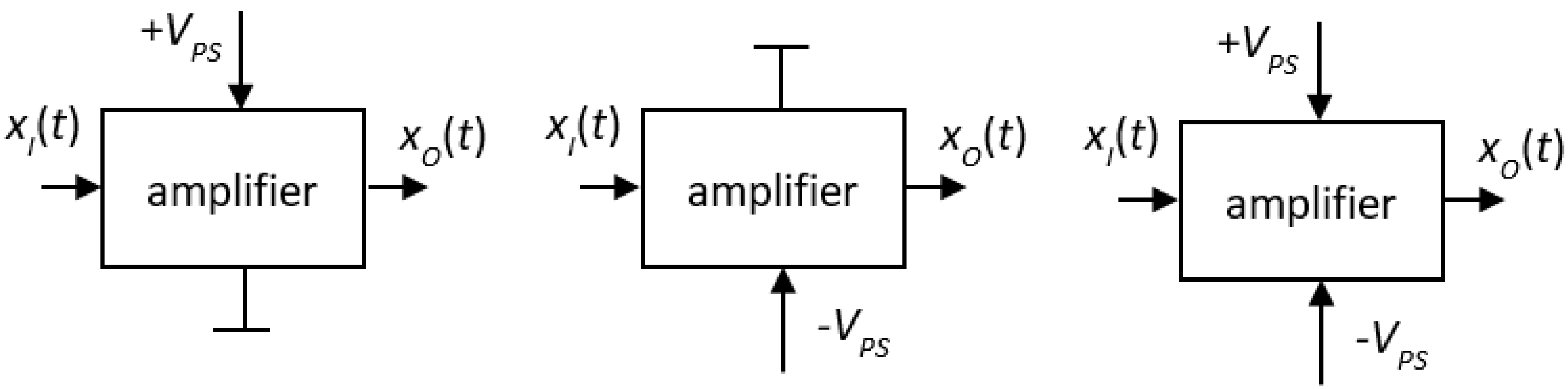
➢ Types of supply

The supply is provided by dc voltage and/or current sources. Voltage sources are most commonly used.

Two source supply

Single source supply

(symmetric differential)

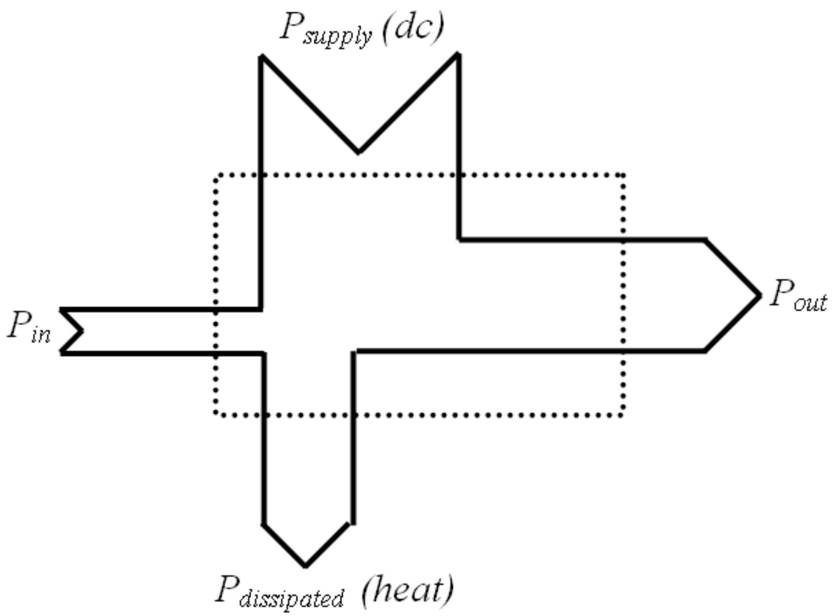


➢ Power transfer and power balance

The average power of the output signal is greater than the average power of the input signal:

$$P_{out} > P_{in}$$

The excess of the output power is taken from the supply sources.



$$P_{supply} + P_{in} = P_{out} + P_{dissip}$$

$$P_{supply} \approx P_{out} + P_{dissip}$$

Efficiency: $\eta = P_{out}/P_{supply}$

Types of amplifiers

Based on the types of input/output signals (voltage/current):

- voltage amplifier $A_v = v_o/v_I$ - dimensionless
- current amplifier $A_i = i_o/i_I$ - dimensionless
- transconductance amplifier $A_{i/v} = i_o/v_I$ – [S], [mS]
- transresistance amplifier $A_{v/i} = v_o/i_I$ – [Ω], [kΩ]

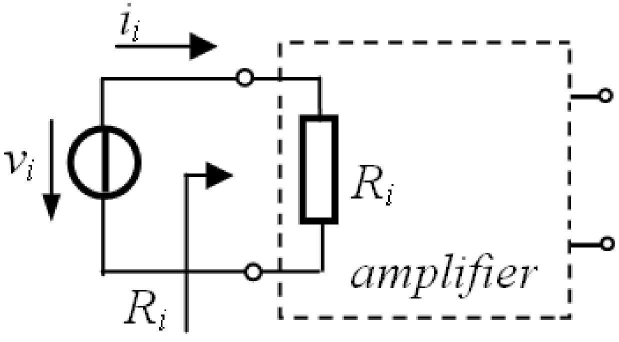
Amplifier parameters

- Gain (forward transfer factor)
  - Analyze the circuit, by using circuit theorems and equation (Kirchhoff, Ohm, Millman)
  - Express the output signal as a function of the input signal, then compute the gain

$$A = \frac{x_O(t)}{x_I(t)}$$

- Input resistance

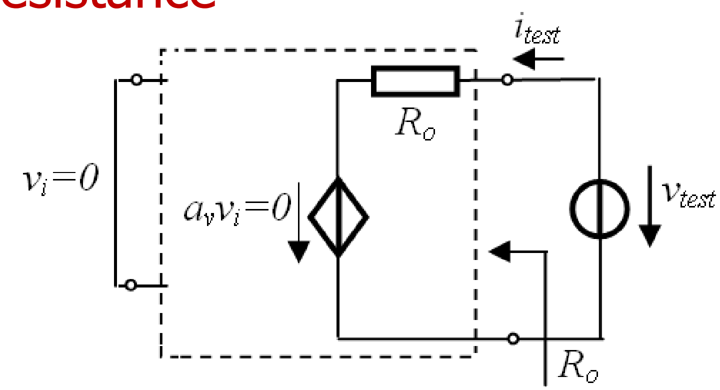
$$R_i = \frac{v_i}{i_i}$$



➢ Amplifier parameters

- **Output resistance**

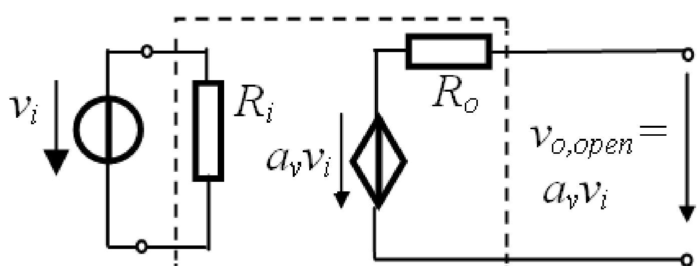
#1



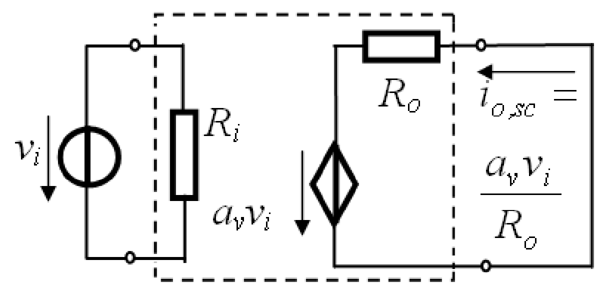
- Set the input signal source to zero
- Connect a test source at the output

$$R_o = \frac{v_{test}}{i_{test}}$$

#2



open circuit



short-circuit

$$R_o = \frac{v_{o,open}}{i_{o,sc}}$$

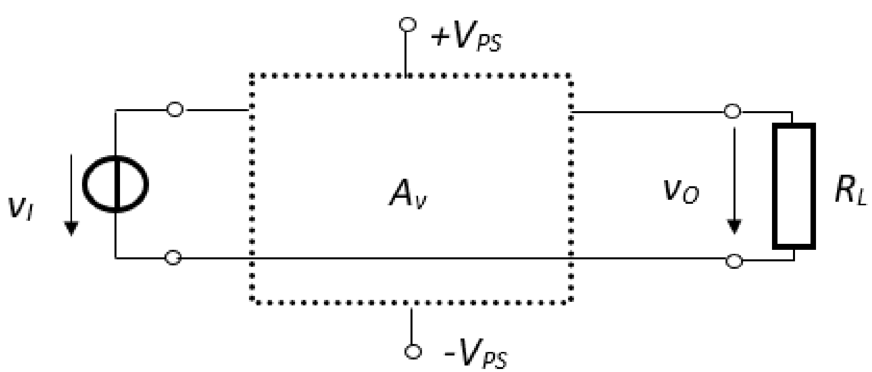
Amplifier parameters

- Active region – range of values for v_I for which the output preserves the shape of the input (no clipping/saturation)

  - ideal amplifier: $V_{OL} = -V_{PS}$; $V_{OH} = +V_{PS}$
  - general-purpose OpAmp $v_O \in (-V_{PS} + 1\text{V}...2\text{V}; +V_{PS} - 1\text{V}...2\text{V})$
  - rail-to-rail OpAmp: $v_O \in \left(-V_{PS}; +V_{PS}\right)$

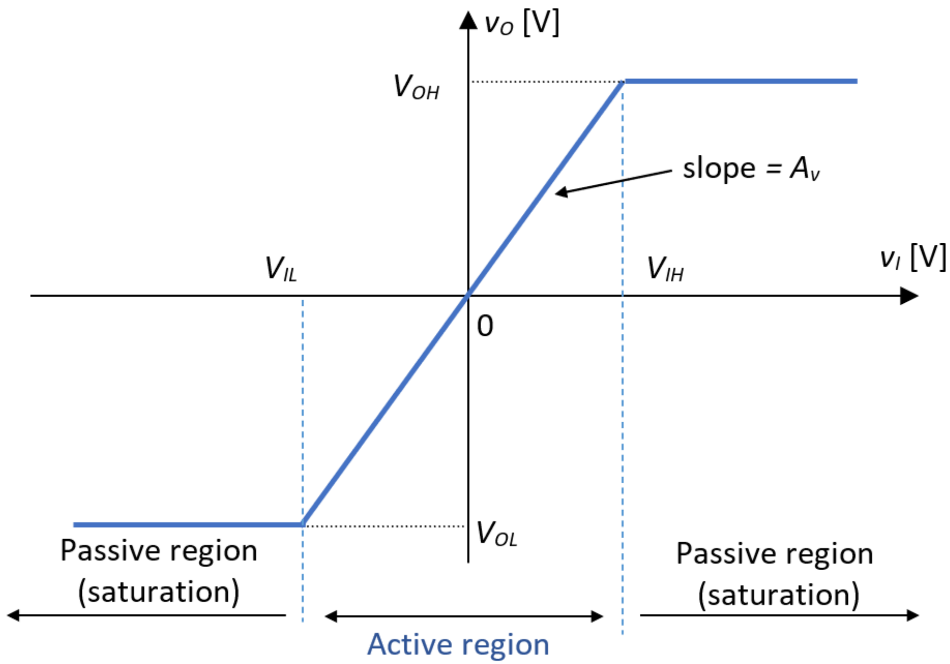
➢ Amplifier parameters

- Active region – differential supply



$$v_I \in \left(\frac{V_{OL}}{A_v}; \frac{V_{OH}}{A_v} \right);$$

$$v_O \in \left(V_{OL}; V_{OH} \right)$$

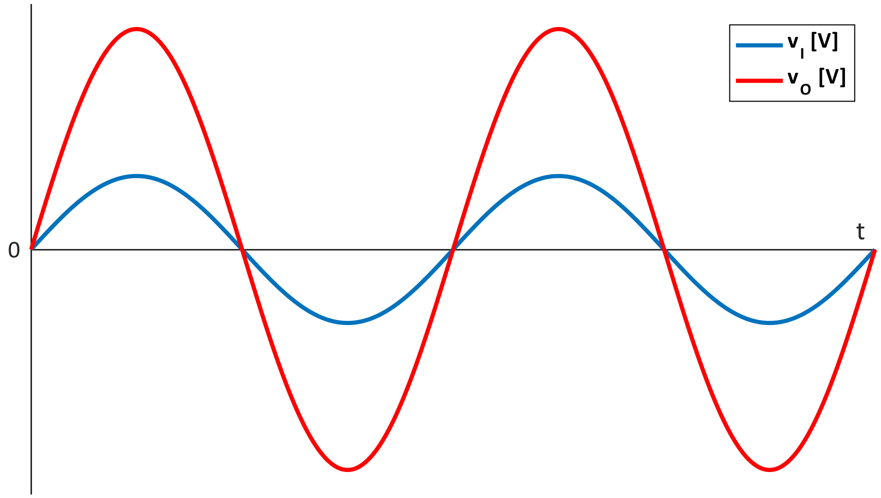


➢ Amplifier parameters

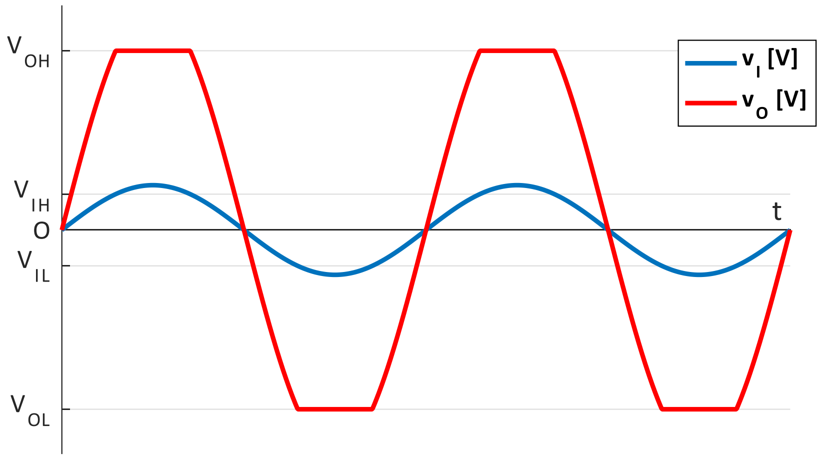
- Active region – differential supply

Waveforms for input in

active region

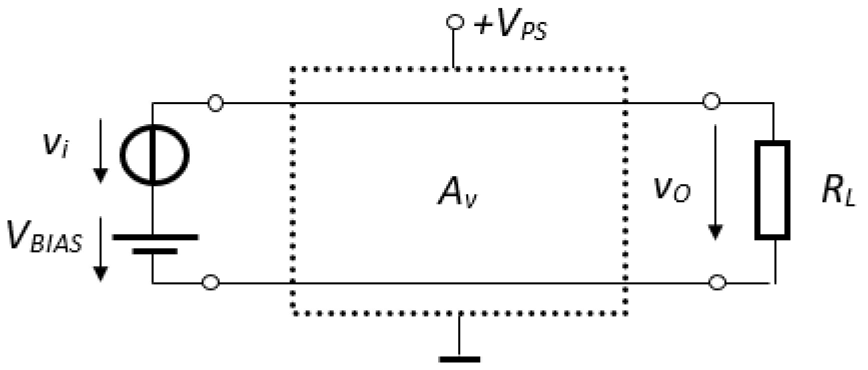


active and passive (saturation)

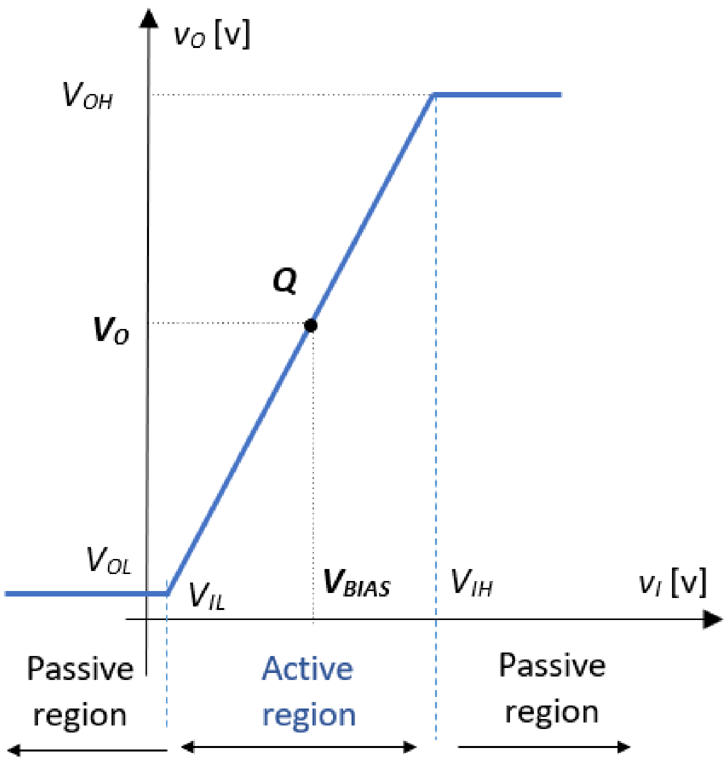


Amplifier parameters

- Active region – unipolar supply



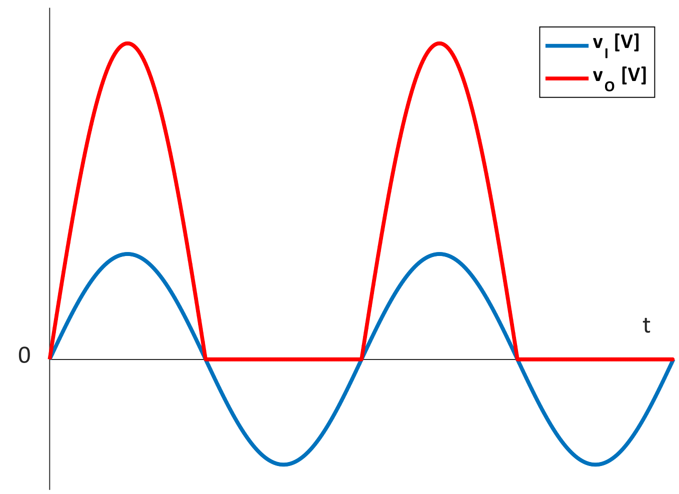
$$v_I \in \left(\frac{V_{OL}}{A_v};\frac{V_{OH}}{A_v}\right);$$
$$v_O \in \left(V_{OL};V_{OH}\right)$$



Amplifier parameters

- Active region – unipolar supply

Waveforms for input in active region



➢ Modeling the voltage amplifier

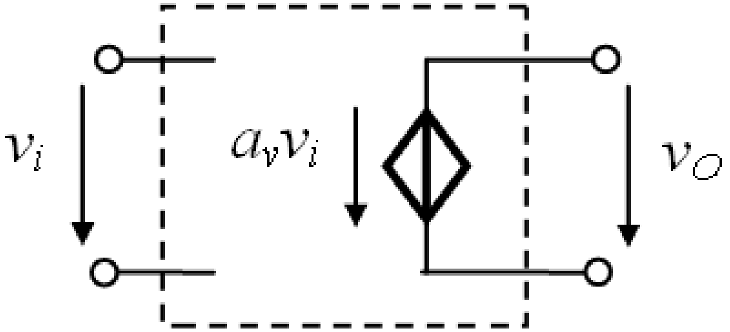
- two-port networks: only the behavior of the input and output ports is explicitly taken into account, and the input-output signal transfer
- valid regardless of the internal complexity of the amplifiers
- valid in the bandpass frequency domain

Linear controlled sources

- active two-port network
- only one finite, non-zero parameter: forward transfer parameter (gain)
- the output signal is controlled by the input signal
- pseudo-sources

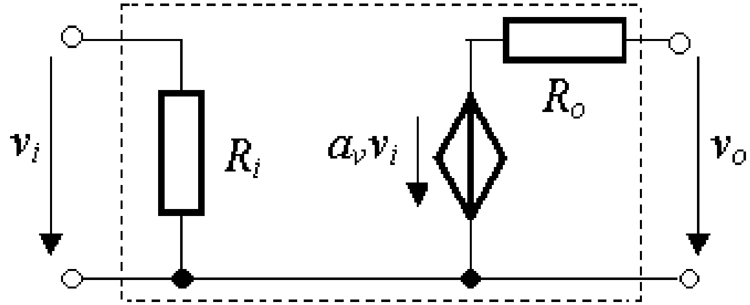
VCVS (voltage controlled voltage source)

$$v_O = a_v v_i$$



➤ Modeling the voltage amplifier

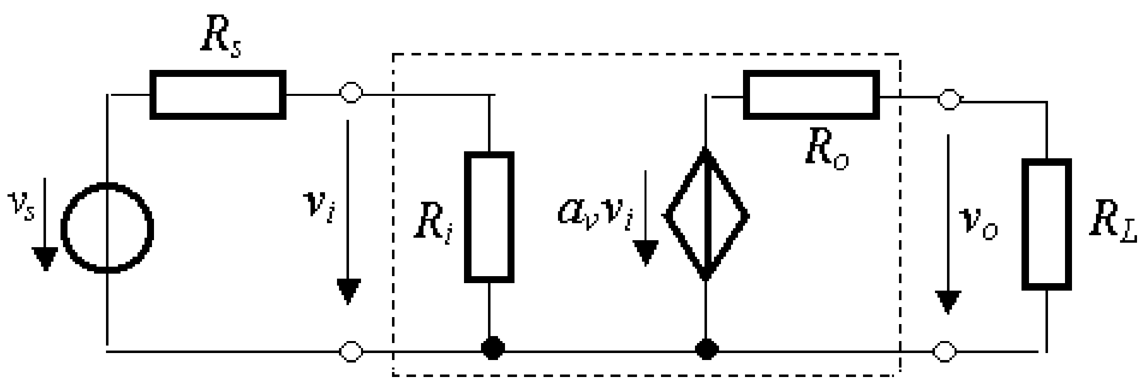
Amplifier model



$$a_v = \frac{v_o}{v_i}$$

a_v – open circuit gain
R_i – draws current from v_i
R_o – deteriorates v_o in the presence of load

Amplifier model connected in a circuit

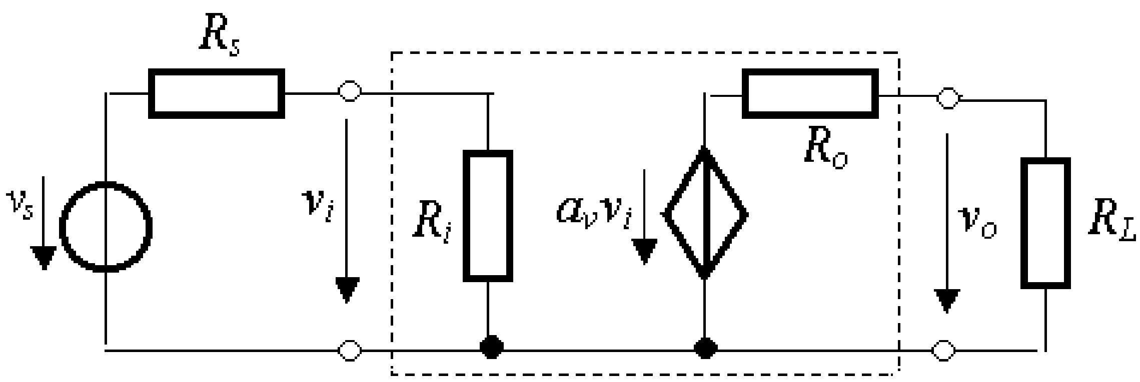


$$A_v = \frac{v_o}{v_s}$$

$$A_v = \frac{R_i}{R_s + R_i} \frac{R_L}{R_L + R_o} a_v$$

Ideal amplifier?

➢ Modeling the voltage amplifier



$$A_v = \frac{v_o}{v_s}$$

$$A_v = \frac{R_i}{R_s + R_i} \frac{R_L}{R_L + R_o} a_v$$

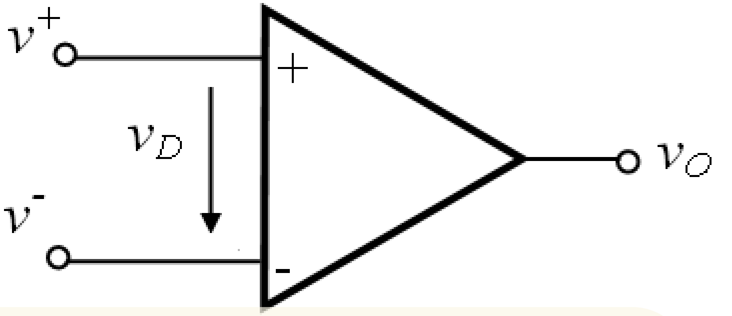
A_v is closer to the open circuit gain a_v when the voltage losses at the input (across R_s) and at the output (across R_o) are reduced.

- $R_i >> R_s$ – the source voltage is transferred to the input $v_i \approx v_s$
- $R_o << R_L$ - the voltage of the VCVS is transferred to the output $v_o \approx a_v v_i$

Ideal voltage amplifier: **$R_i = \infty$; $R_o = 0$**

Amplifiers with OpAmp

$$v_O = av_D = \infty \cdot v_D$$



I. Utilization as comparator, in switching mode

C6 + C7

$$v_O \in \{V_{OL}\, ; V_{OH}\}$$

$v_D > 0$, $v_O \rightarrow +\infty$, v_O limited by the positive supply $v_O = V_{OH} \approx +V_{PS}$

$v_D < 0$, $v_O \rightarrow -\infty$, v_O limited by the negative supply $v_O = V_{OL} \approx -V_{PS}$

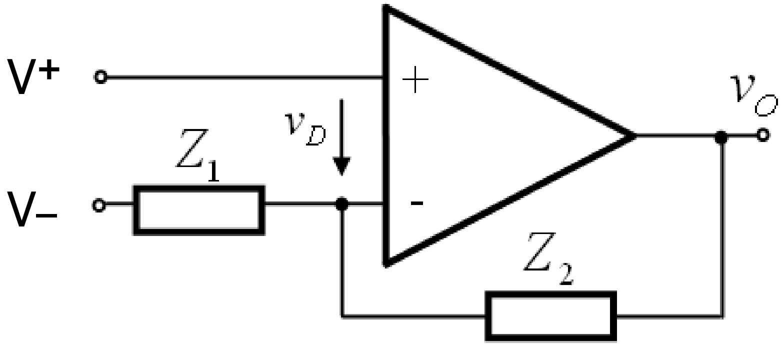
II. Utilization as amplifier

$$v_O \in (V_{OL}\, ; V_{OH})$$

It is mandatory that $v_D = 0$, so then $v_O = a \cdot v_D = \infty \cdot 0$ – indeterminate

v_D is kept at 0 by means of external components (R) arranged in a negative feedback **(NF)** configuration

Amplifiers with OpAmp



$$v_O = a v_D$$

$a \to \infty$ for ideal op-amp

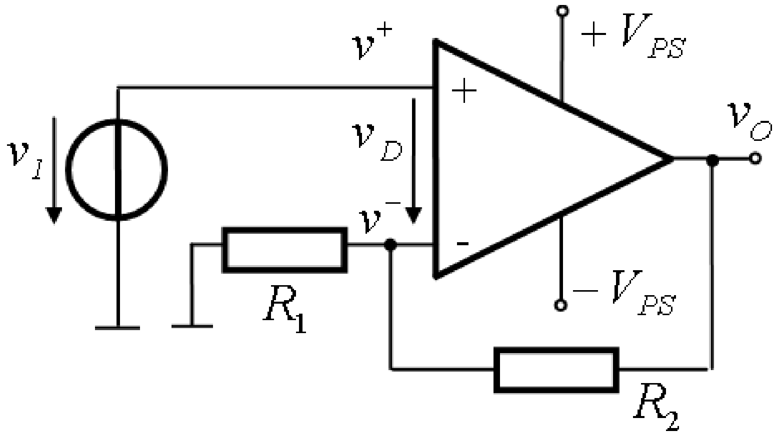
$$v_D = 0 \qquad \underline{v_D \uparrow}, v_O \uparrow, v^- \uparrow, \underline{v_D \downarrow}$$

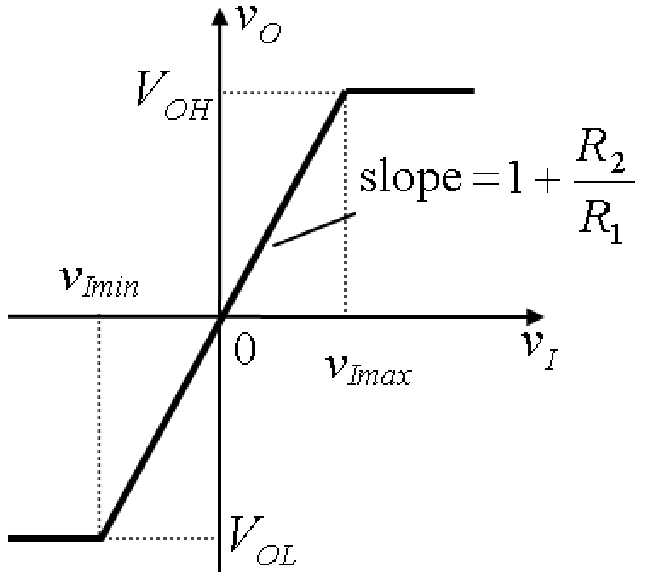
NF automatically keeps v_D at zero

v^+	v^-	**Amplifier**
v_I	ground	non-inverting
ground	v_I	inverting
v_{I1}	v_{I2}	differential

Amplifiers with OpAmp

Non-inverting amplifier



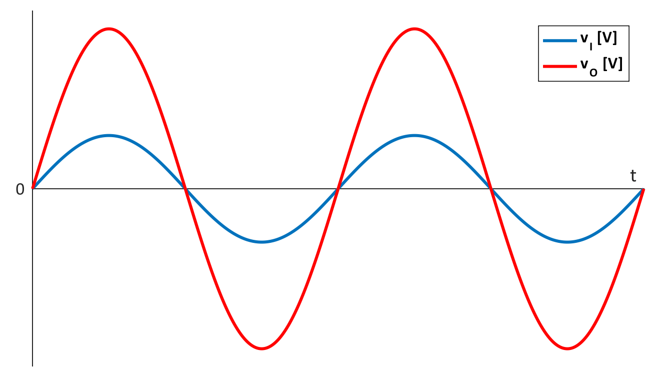


$$v^- = \frac{R_1}{R_1 + R_2} v_O$$

$$v_D = v^+ - v^- = v_I - \frac{R_1}{R_1 + R_2} v_O = 0$$

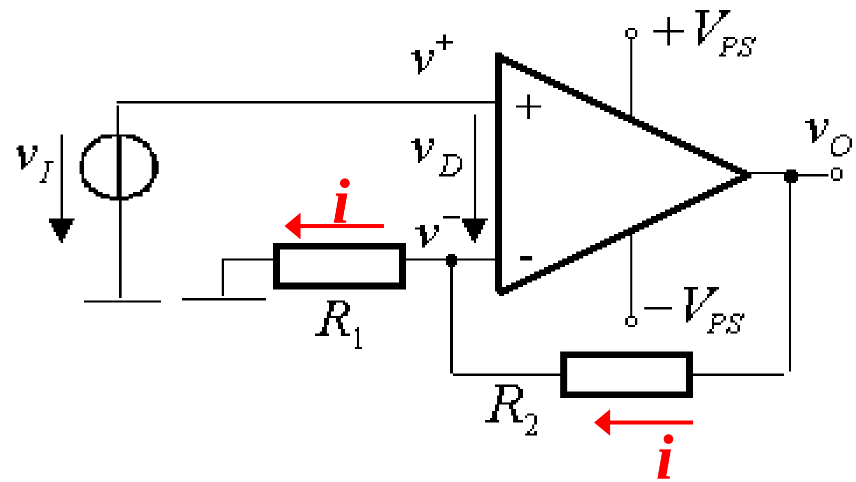
$$v_I = \frac{R_1}{R_1 + R_2} v_O$$

$$A_v = \frac{v_O}{v_I} = 1 + \frac{R_2}{R_1}$$



Amplifiers with OpAmp

➢ Non-inverting amplifier



Alternative method for computing A_v

$$\left.\begin{array}{l} v_D = 0 \\ v^+ = v_I \end{array}\right\} \Rightarrow v^- = v_I$$

The same current goes through R_1 and R_2

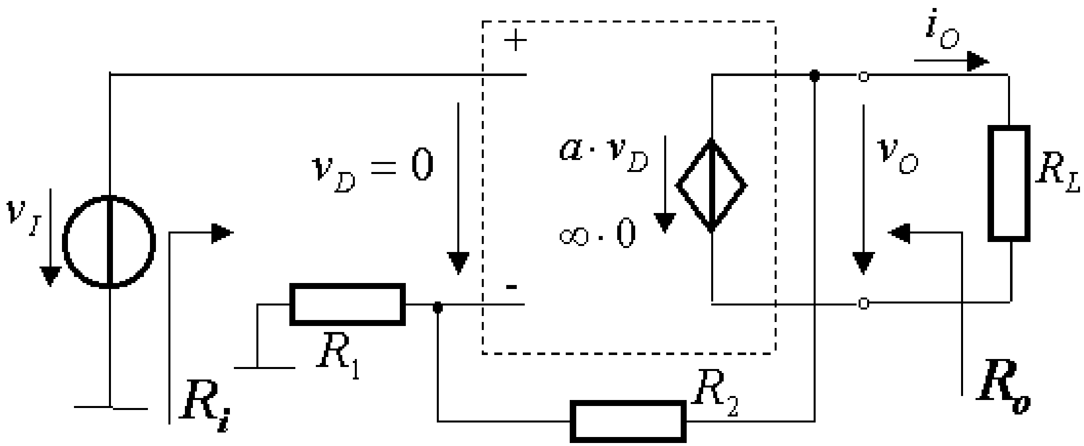
$$\frac{v_I}{R_1} = \frac{v_O - v_I}{R_2} \qquad A_v = \frac{v_O}{v_I} = 1 + \frac{R_2}{R_1}$$

Direct consequences of NF for an OpAmp with very high intrinsic gain ($a \to \infty$ for ideal op-amp):

- gain is set only by the ratio of two resistors (external components)
- the gain value: precise and stable
- the gain is independent of the OpAmp, it is not influenced by the technological spread of the OpAmp's parameters

➢ Non-inverting amplifier

Input and output resistances



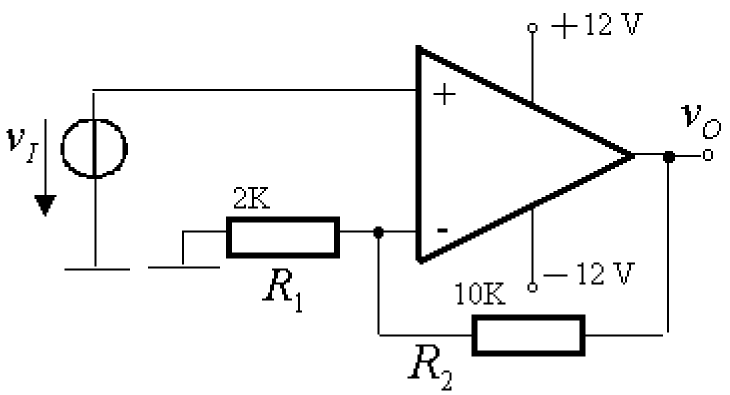
Computed on the equivalent model

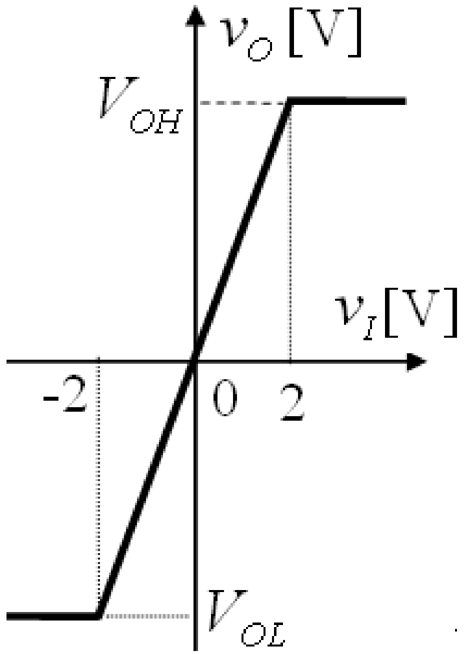
v_I sees an open circuit, so $\mathbf{R_i = \infty}$

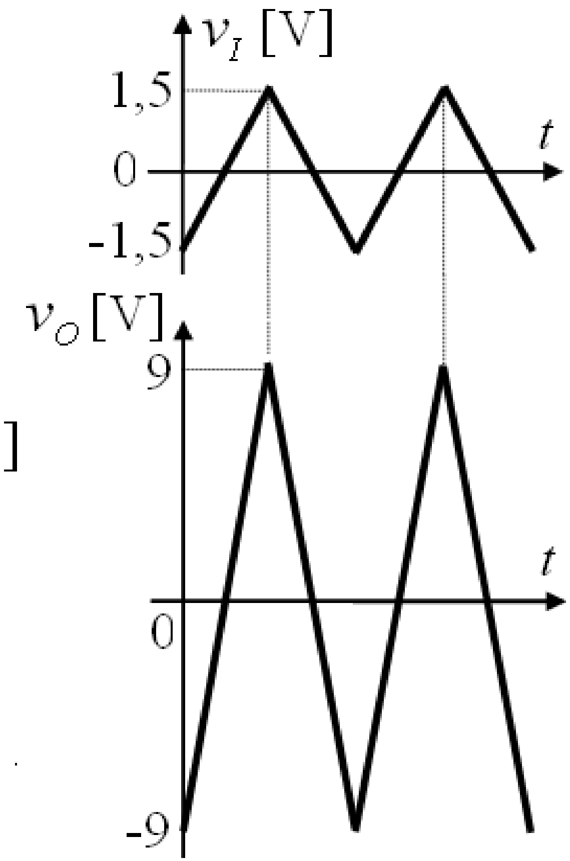
$$R_o = \frac{v_{O_{open}}}{i_{O_{sc}}} = \frac{v_{O_{open}}}{\infty} = 0$$

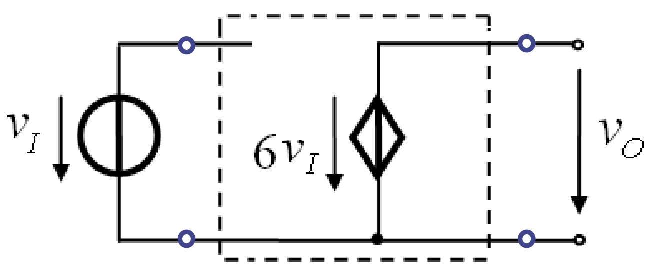
- Non-inverting amplifier

Example





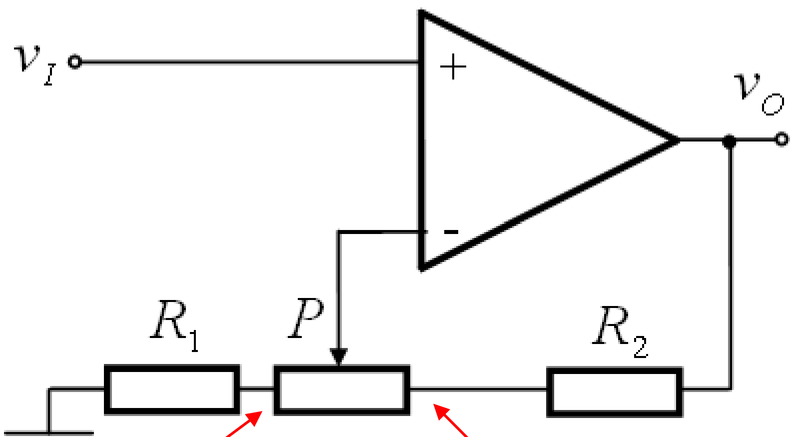




- $v_O(t)$ for triangular $v_I(t)$, 3 V amplitude

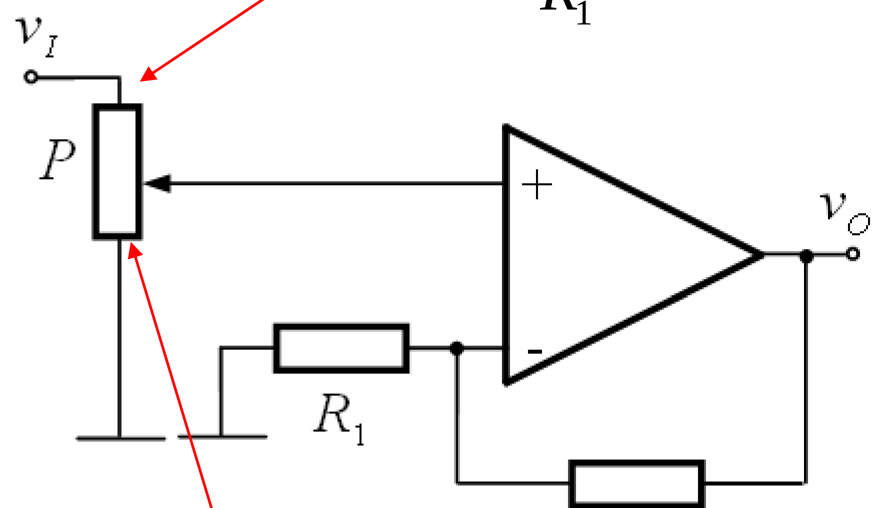
➢ Non-inverting amplifier

Adjustable gain



$$A_{v_{max}} = 1 + \frac{R_2 + P}{R_1}$$

$$A_{v_{min}} = 1 + \frac{R_2}{R_1 + P}$$



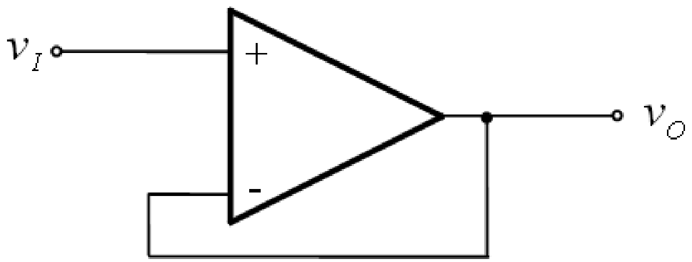
$$A_{v_{max}} = 1 + \frac{R_2}{R_1}$$

$$A_{v_{min}} = 0$$

Amplifiers with OpAmp

➢ Non-inverting amplifier

Voltage follower



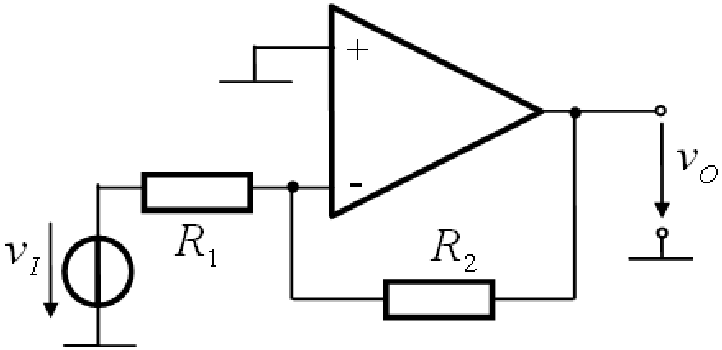
$$v_O = v_I$$

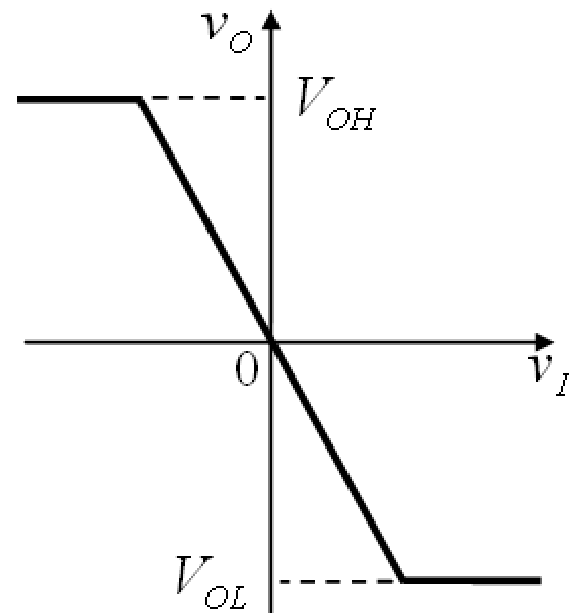
the output voltage follows the input voltage

- total (full) NF
- no voltage gain ($A_v = 1$)
- infinite current gain ($A_i = \infty$)

Voltage followers are used as a buffer stages between a source (or the output of a circuit) with high R_O (can only supply low current) to a low R_L (needs high current) – impedance matching.

- Inverting amplifier



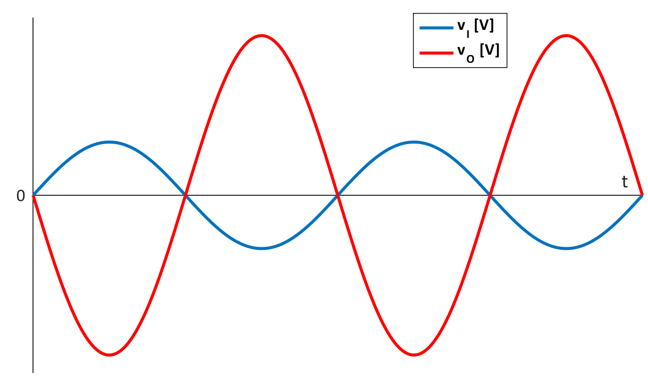


$$v^+ = 0$$

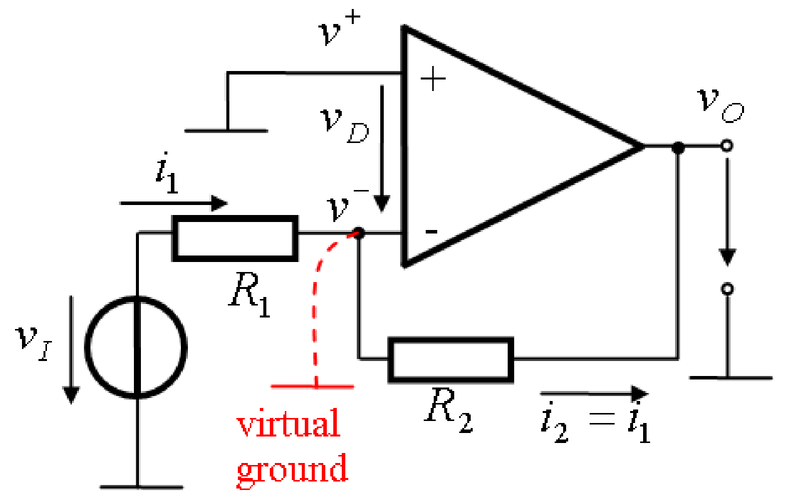
$$v^- = \frac{R_2}{R_1 + R_2} v_I + \frac{R_1}{R_1 + R_2} v_O$$

$$v_D = v^+ - v^- = 0 - \frac{R_2}{R_1 + R_2} v_I - \frac{R_1}{R_1 + R_2} v_O = 0$$

$$A_v = \frac{v_O}{v_I} = -\frac{R_2}{R_1}$$



➢ Inverting amplifier



Alternative method for computing A_v

NF => $v_D = 0$

$$v^+ = v^-, \quad v^+ = 0 \quad \Rightarrow \quad v^- = 0$$

virtual ground

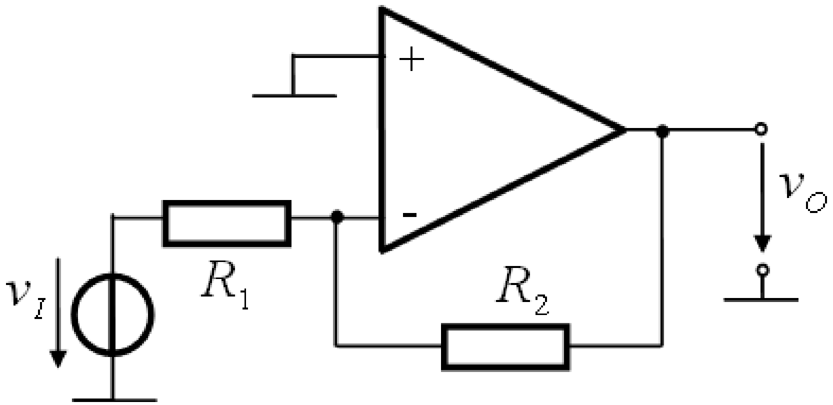
$$i_1 = i_2 \qquad i_1 = \frac{v_I - 0}{R_1} \qquad i_2 = \frac{0 - v_O}{R_2}$$

$$\frac{v_I}{R_1} = -\frac{v_O}{R_2}$$

$$A_v = \frac{v_O}{v_I} = -\frac{R_2}{R_1}$$

➢ Inverting amplifier

Input and output resistances



The input source "sees" only R_1 (the inverting input is virtual ground)

$$R_i = R_1$$

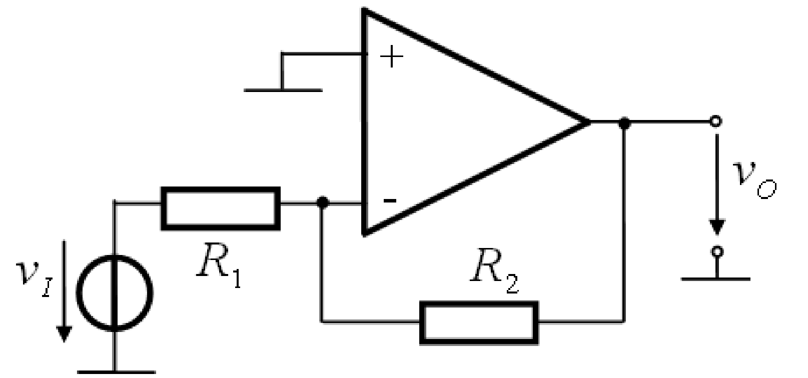
$$R_o = 0$$

- Noninverting amplifier: $R_i \to \infty$
- Inverting amplifier: $R_i \to$ finite (units, tens of kΩ)

➢ Inverting amplifier

Example

R_1 = 10 K, R_2 = 100K, supply ± 12 V



✓Compute R_i, R_o, A_v
✓Find v_I range for active region
✓ Plot VTC for v_I in [-5, 5].
✓Plot v_I and v_O for v_I – sinewave, 1 V and then 2 V amplitude.

$$R_i = R_1 = 10\text{k} \qquad A_v = -\frac{R_2}{R_1} = -\frac{100}{10} = -10$$

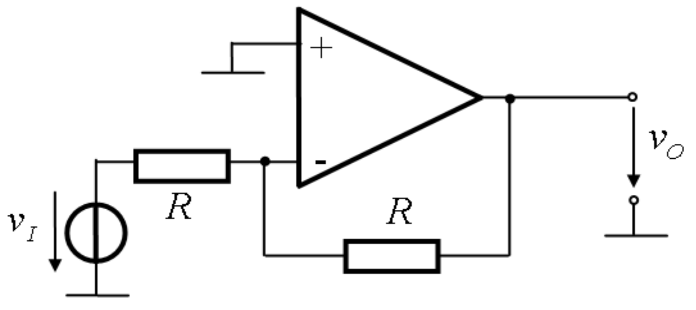
$$R_o = 0$$

v_I range: $(-1.2\text{V}; +1.2\text{V})$

Amplifiers with OpAmp

➢ Inverting amplifier

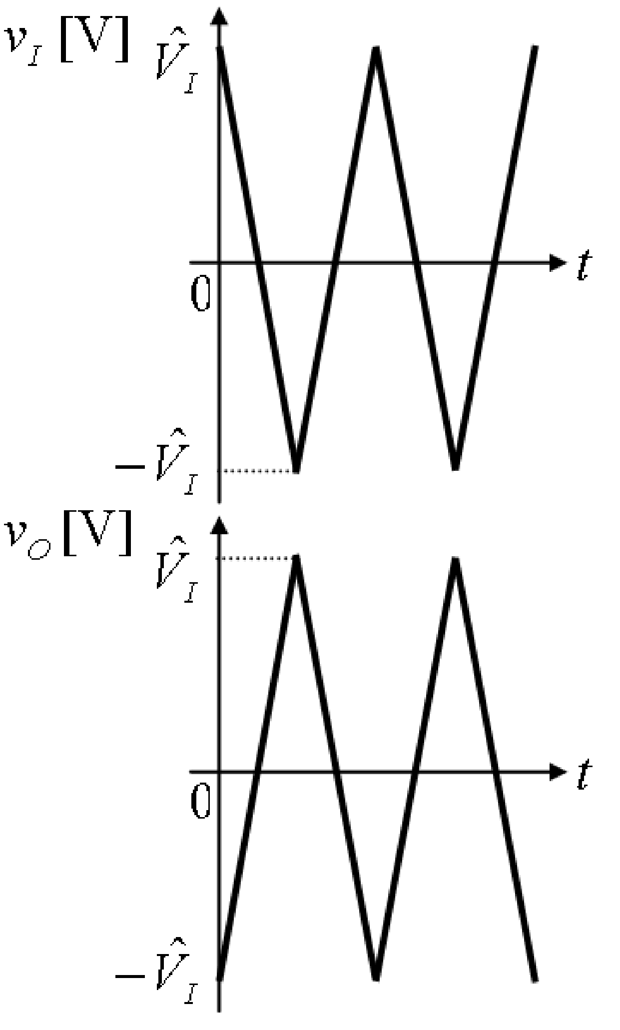
Voltage follower



$$v_O = -v_I$$

$$A_v = \frac{v_O}{v_I} = -1$$

$$R_i = R$$



Summary

The *little black bug* (OpAmp) is also able to make:

- Electronic amplifiers
- Amplifiers with OpAmp
  - Non-inverting amplifier
  - Inverting amplifier

Next week: Summing and differential amplifiers with OpAmp.