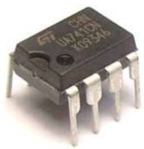
LU3EE200
Techniques et dispositifs pour l'électronique analogique et numérique

Chapitre n° 2 :
L'Amplificateur Opérationnel Réel et ses applications

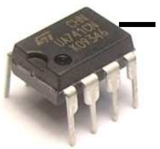


Un peu d'histoire

- Concept présenté en 1947, par John R. Ragazzini
  - « As an amplifier so connected can perform the mathematical operations of arithmetic and calculus on the voltages applied to it's input, it is hereafter termed an « Operational Amplifier » », Analysis of problems in dynamics by electronic circuits, Proceedings of the IRE, vol. 35, mai 1947, p. 444
- Premiers AOP (Bob Widlar / Fairchild)
  - µA702 (1963) 300$
  - µA709 (1965) 70$ → 6$
  - µA741 (1968, David Fullagar) → 2$
    - Compensé en fréquence

  BJT

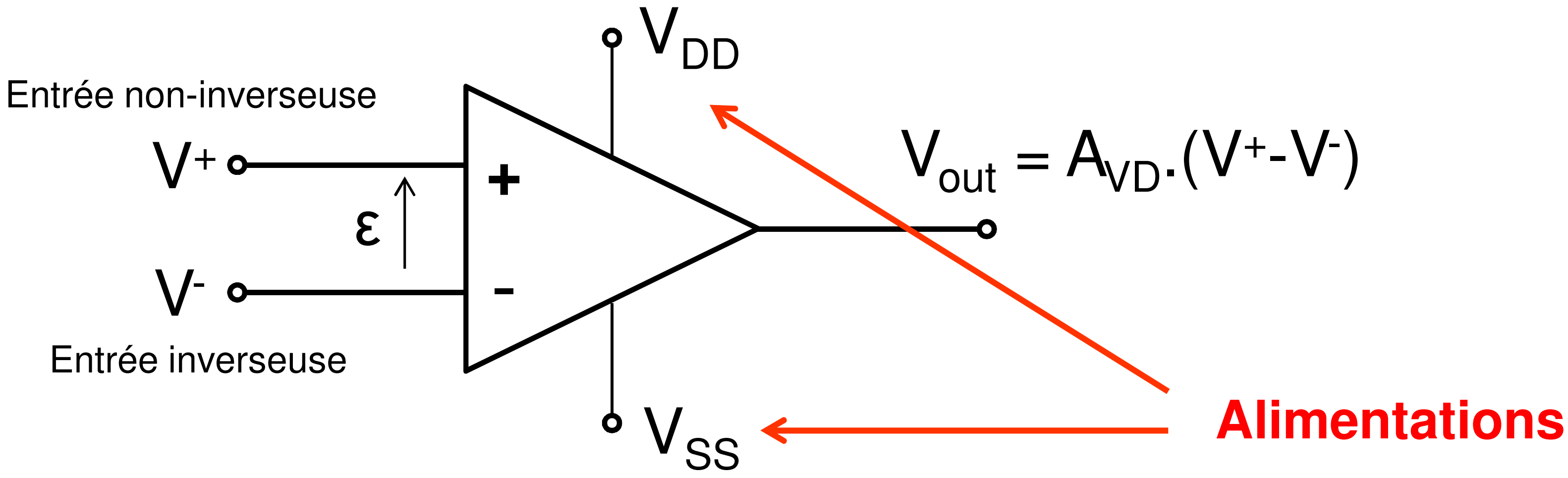
  - TL081, TL082, TL084 (Années 70) — **BiFET**
  - CA3140 (Années 70) — **BiMOS**



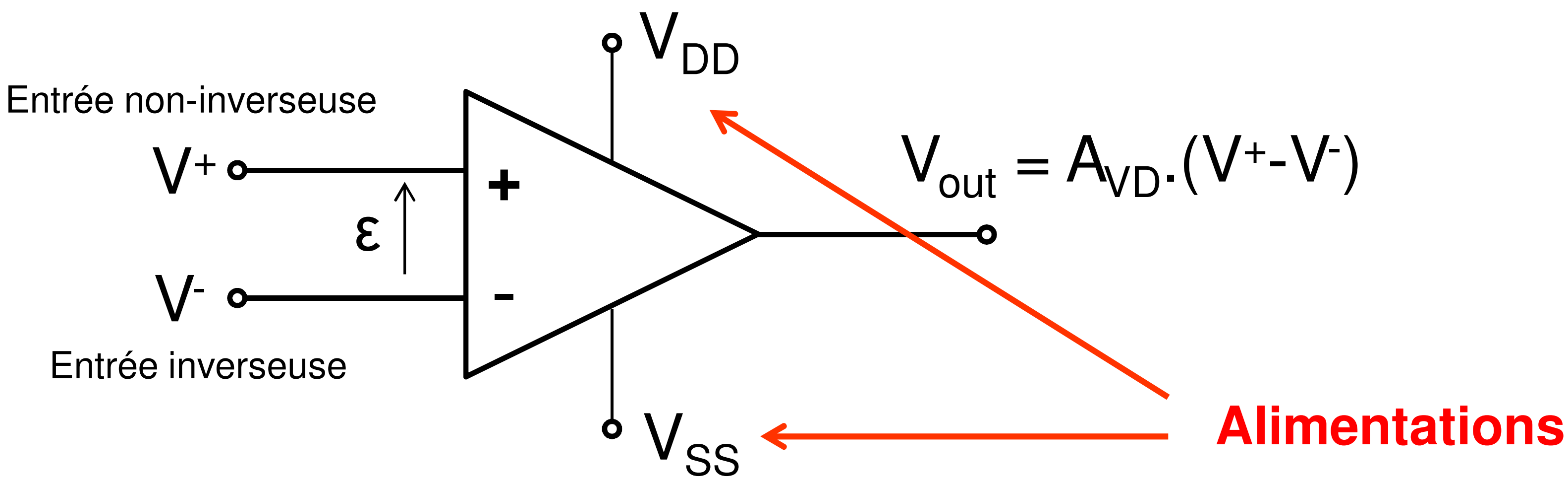
Un peu d'histoire

Référence	Type	Impédance d'entrée	Courants d'entrée	Slew Rate	Produit Gain Bande	Courant de court circuit
µA741	Bipolaire	2 MΩ	80nA	0,5 V/µs	1 Mhz	25mA
TL081	Bifet	$10^{12}\Omega$	20nA	16 V/µs	4 Mhz	40mA
CA3140	Bimos	$10^{12}\Omega$	10pA	9 V/µs	4,5Mhz	40mA

AOP et AOP idéal

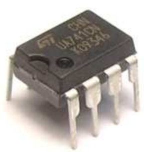


AOP et AOP idéal



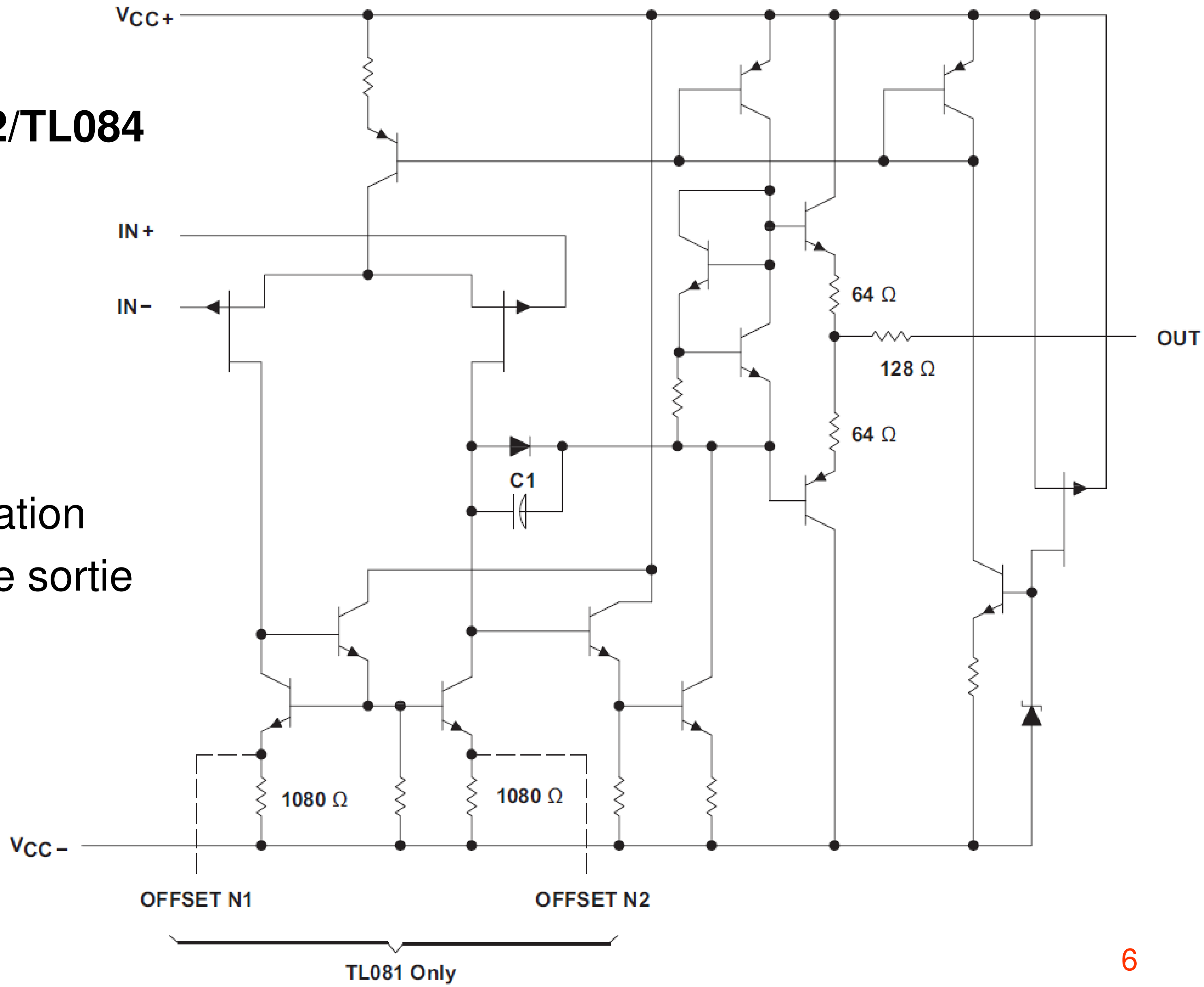
AOP idéal :

- A_{VD} ∞ → en régime **linéaire** $V^+ = V^-$
- Z_{in} ∞ → $I^+ = I^- = 0$
- $Z_{out} = 0$
- Pas de délais, transition nulle
- $V_{SS} \leq V_{out} \leq V_{DD}$



Structure interne

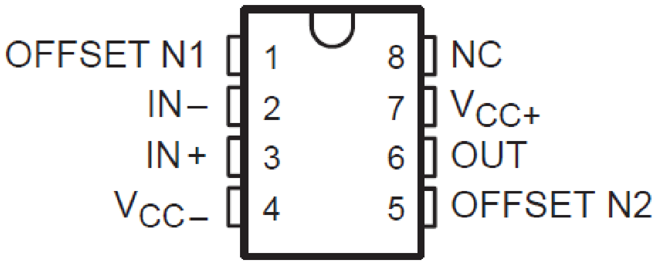
TL081/TL082/TL084



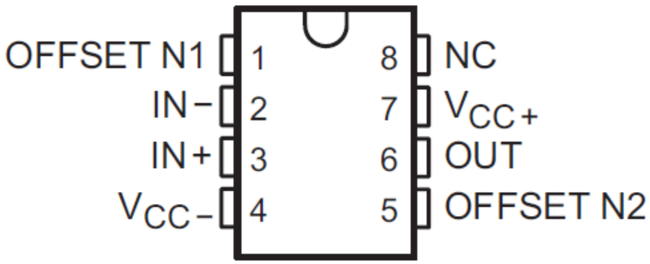
- 3 étages
  - 2 étages d'amplification
  - 1 étage de sortie

AOP Idéal vs AOP Réel

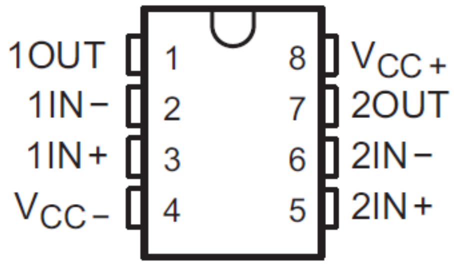
µA741M . . . JG PACKAGE
µA741C, µA741I . . . D, P, OR PW PACKAGE
(TOP VIEW)



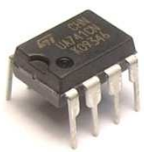
TL081, TL081A, TL081B
D, P, OR PS PACKAGE
(TOP VIEW)



TL082, TL082A, TL082B
D, JG, P, PS, OR PW PACKAGE
(TOP VIEW)



NC − No internal connection



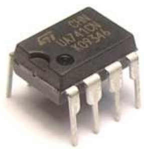
1 AOP sur un CI

2 AOP sur un CI

AOP Idéal vs AOP Réel

$V_{CC\pm} = \pm 15V$, $T_A = 25°C$

	AOP idéal	**µA741C**
A_{VD} Large-signal differential voltage amplification	∞	200V/mV (RL ≥ 2kΩ)
R_i Input resistance	∞	2MΩ (typ)
R_o Output resistance	0Ω	75Ω (typ)



AOP Idéal vs AOP Réel

$V_{CC\pm}$ = ±15V, T_A = 25°C

	AOP idéal	µA741C
A_{VD} Large-signal differential voltage amplification	∞	200V/mV ($RL \geq 2k\Omega$)
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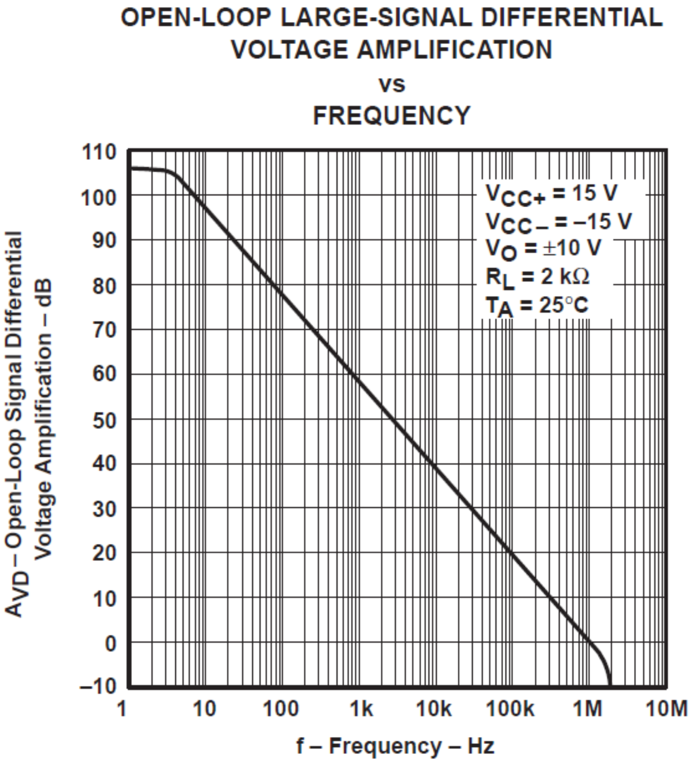


$$A_{VD} = \frac{A_0}{\left(1+\frac{jf}{f_0}\right)} \cdot \frac{1}{\left(1+\frac{jf}{f_1}\right)} \cdot \frac{1}{\left(1+\frac{jf}{f_2}\right)}$$

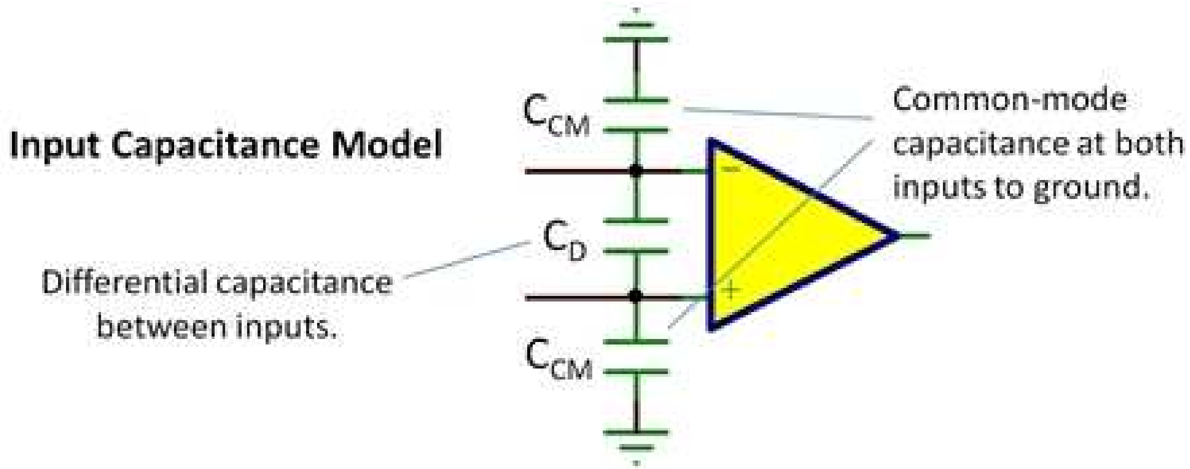
$$\boxed{A_{VD} \approx \frac{A_0}{\left(1+\frac{jf}{f_0}\right)}}$$

Valeurs typiques : $A_0 = 10^5$ à 10^6, f_0 = 2 à 20Hz, f_1 autour de 1MHz

AOP Idéal vs AOP Réel

$V_{CC\pm}$ = ±15V, T_A = 25°C

	AOP idéal	µA741C
C_i Input capacitance	-	1,4pF (typ)



C_i est la somme des effets capacitifs « vus » ou modélisés en entrée de l'AOP.

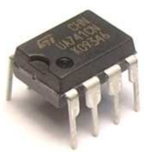
AOP Idéal vs AOP Réel

$V_{CC\pm}$ = ±15V, T_A = 25°C

	AOP idéal	**µA741C**
CMRR	∞	90dB (typ)

$$V_{out} = A_{VD}(V^{+} - V^{-}) + A_C\left(\frac{V^{+}+V^{-}}{2}\right)$$

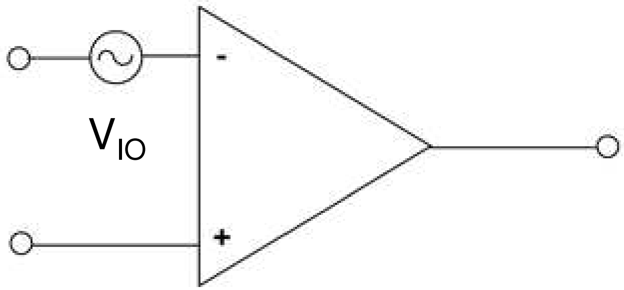
$$\boxed{CMRR = \frac{A_{VD}}{A_C}}$$



AOP Idéal vs AOP Réel

$V_{CC\pm} = \pm 15V$, $T_A = 25°C$

	AOP idéal	**µA741C**
V_{IO} Input offset voltage	-	1mV (typ) 5mV (max)
I_{IO} Input offset current	0nA	20nA (typ)
I_B Input bias current	0nA	80nA (typ)



- **Offset Voltage: The differential voltage which must be applied to the input of an op amp to produce zero output.**

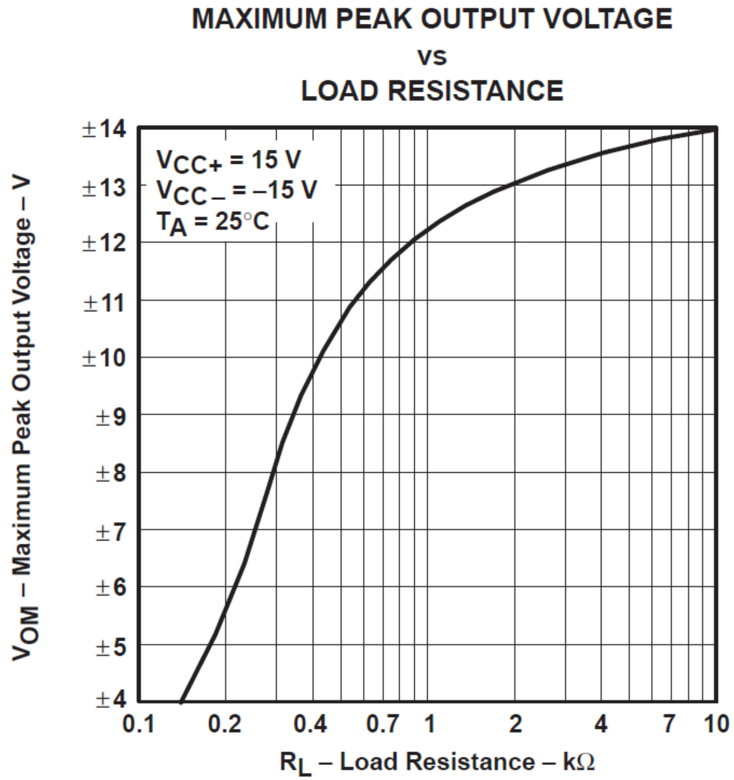
Les valeurs de ces courants étant très petites, on pourra continuer de les négliger

AOP Idéal vs AOP Réel

$V_{CC\pm}$ = ±15V, T_A = 25°C

	AOP idéal	µA741C
V_{ICM} Common-mode input voltage range	±15V	±13V
V_{OM} Maximum peak output voltage swing	±15V	±14V (R_L = 10kΩ) ±13V (R_L = 2kΩ)

En regime non-linéaire la valeur de la charge joue sur les tensions de seuils



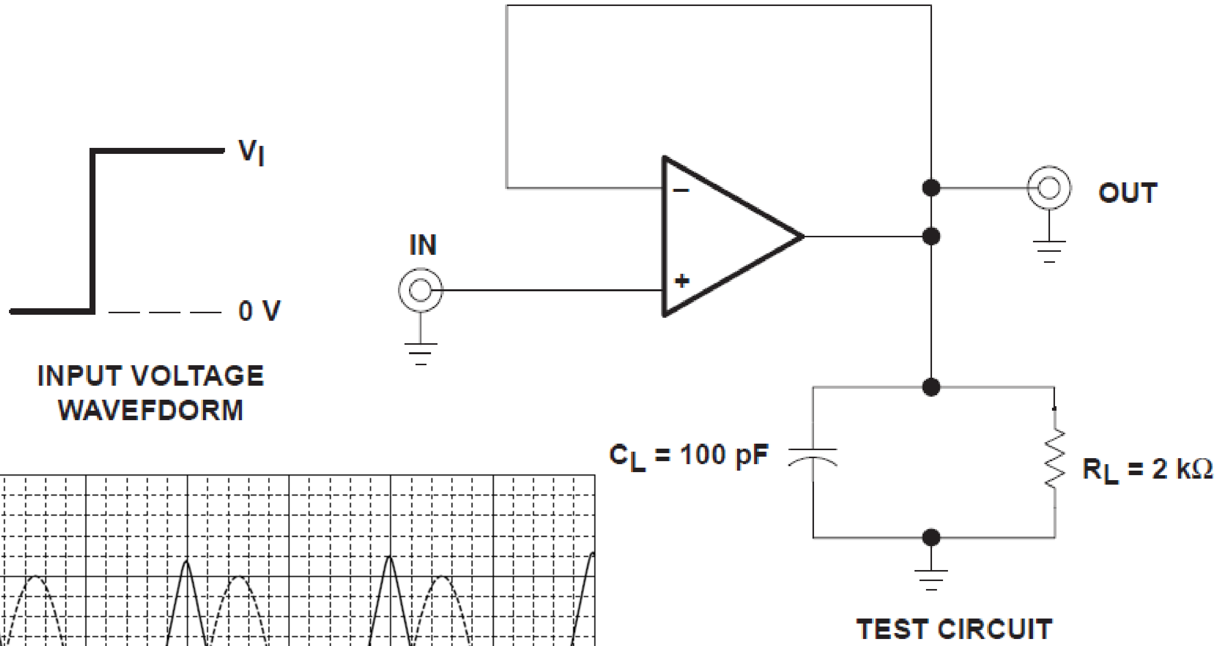
AOP Idéal vs AOP Réel

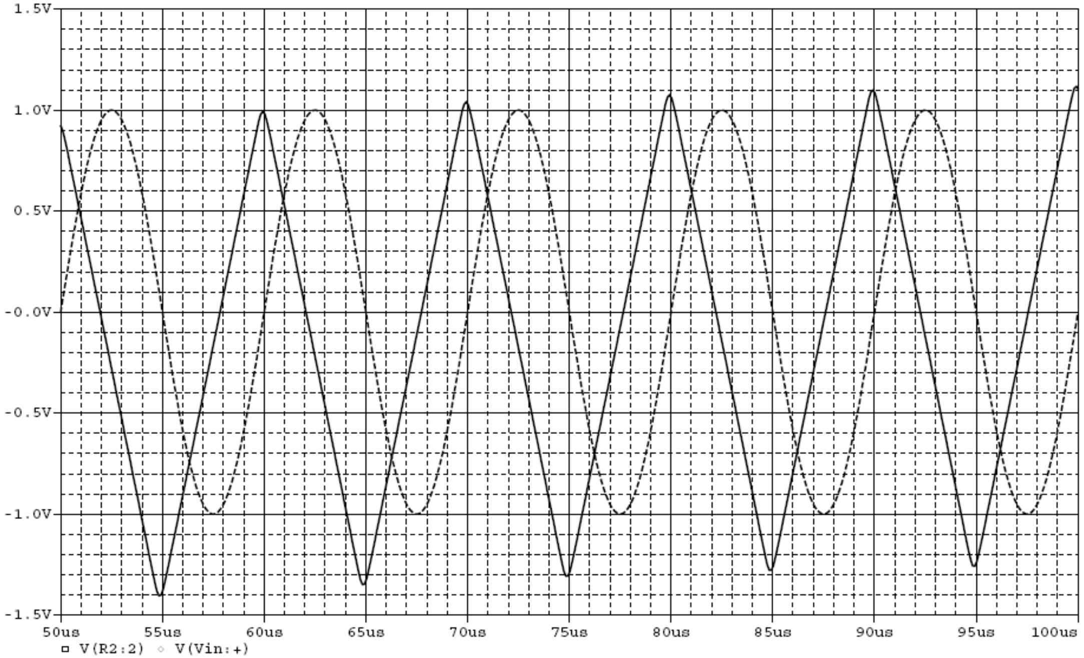
$V_{CC\pm} = \pm 15V$, $T_A = 25°C$

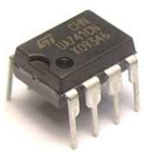
	AOP idéal	**µA741C**
I_{OS} Short-circuit output current	-	±25mA (typ) ±40mA (max)
I_{CC} Supply current (no load, $V_o = 0$)	-	1,7mA (typ) 2,8mA (max)
P_D Total power dissipation (no load, $V_o = 0$)	-	50mW (typ) 85mW (max)

AOP Idéal vs AOP Réel

- Conditions de mesure du Slew-Rate



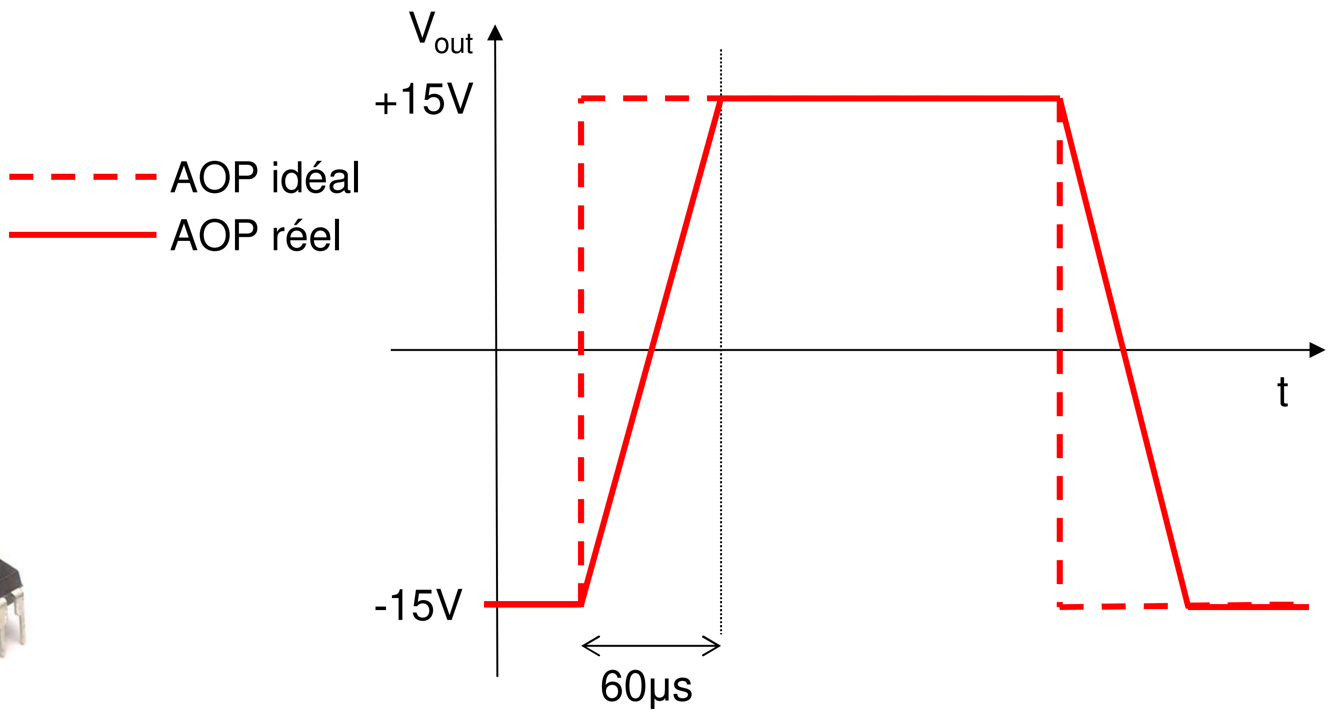




AOP Idéal vs AOP Réel

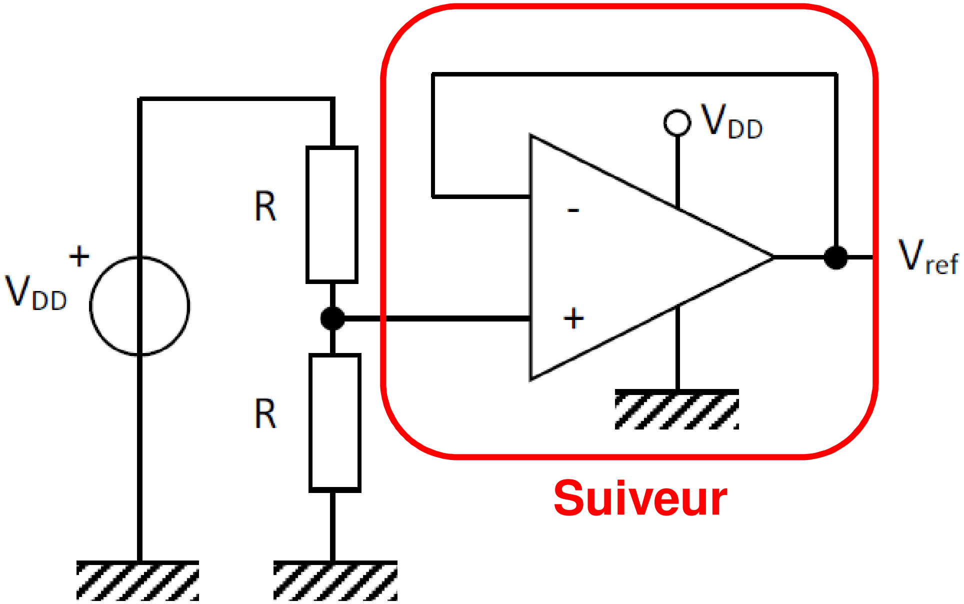
$V_{CC\pm} = \pm 15V, T_A = 25°C$

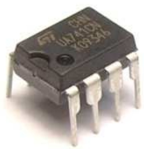
	AOP idéal	**µA741C**
SR Slew rate at unity gain $V_I = 10V$, $C_L = 100pF$ $R_L = 2k\Omega$	0	0,5V/µs



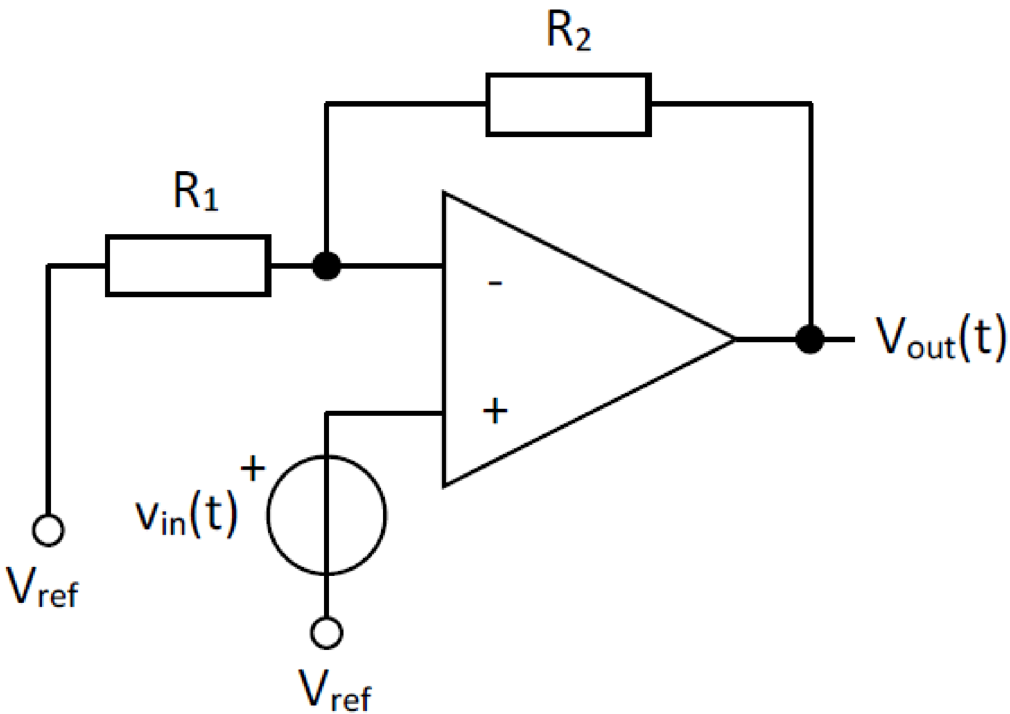
Suiveur

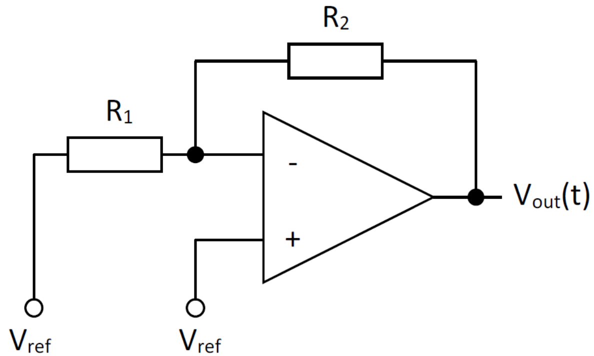
- Tension de référence en mono-alimentation



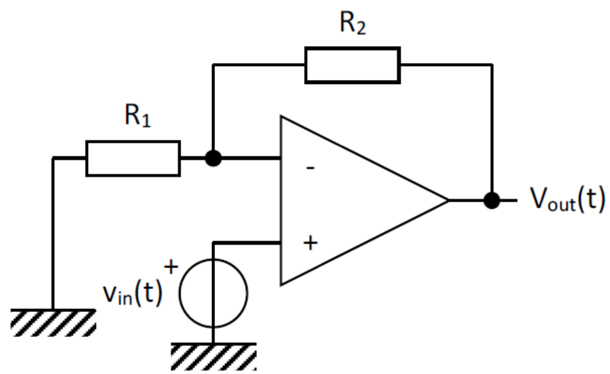


Amplificateur non-inverseur





En courant continu



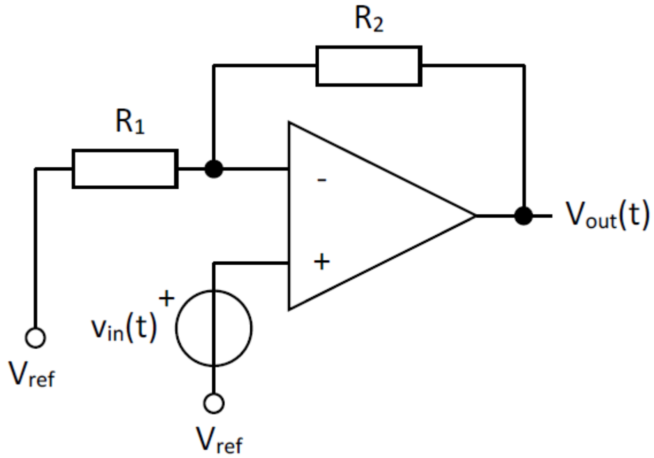
En courant alternatif

$$\boxed{V_{out}(t) = V_{ref} + \frac{A_0.(R_1 + R_2)}{A_0.R_1 + R_1 + R_2} \cdot \frac{1}{1 + \frac{jf}{f_0} \cdot \frac{R_1 + R_2}{A_0.R_1 + R_1 + R_2}} . v_{in}(t)}$$

$$K = + \frac{A_0.(R_1 + R_2)}{A_0.R_1 + R_1 + R_2} \cong + \frac{(R_1 + R_2)}{R_1}$$

$$f_c = f_0 . \frac{A_0.R_1 + R_1 + R_2}{R_1 + R_2}$$

Amplificateur non-inverseur

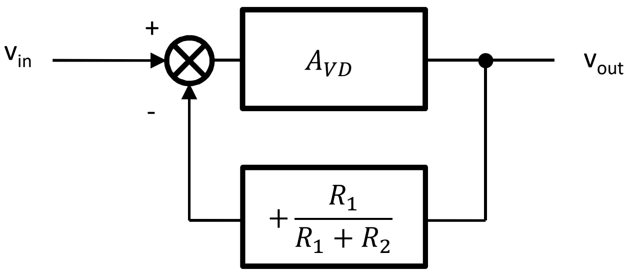


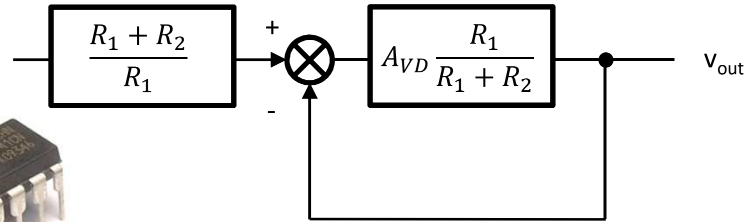
$$V_{out}(t) = V_{ref} + \frac{A_0.(R_1+R_2)}{A_0.R_1+R_1+R_2}.\frac{1}{1+\frac{jf}{f_0}.\frac{R_1+R_2}{A_0.R_1+R_1+R_2}}.v_{in}(t)$$

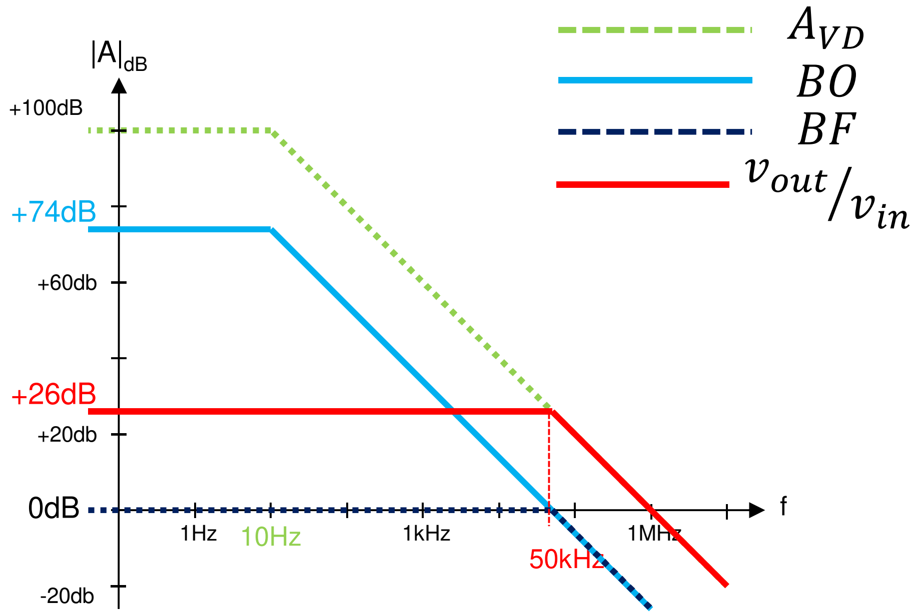
A.N. : $A_0 = 10^5$, $f_0 = 10Hz$, $R_1 = 1k\Omega$, $R_2 = 20k\Omega$

En courant alternatif :

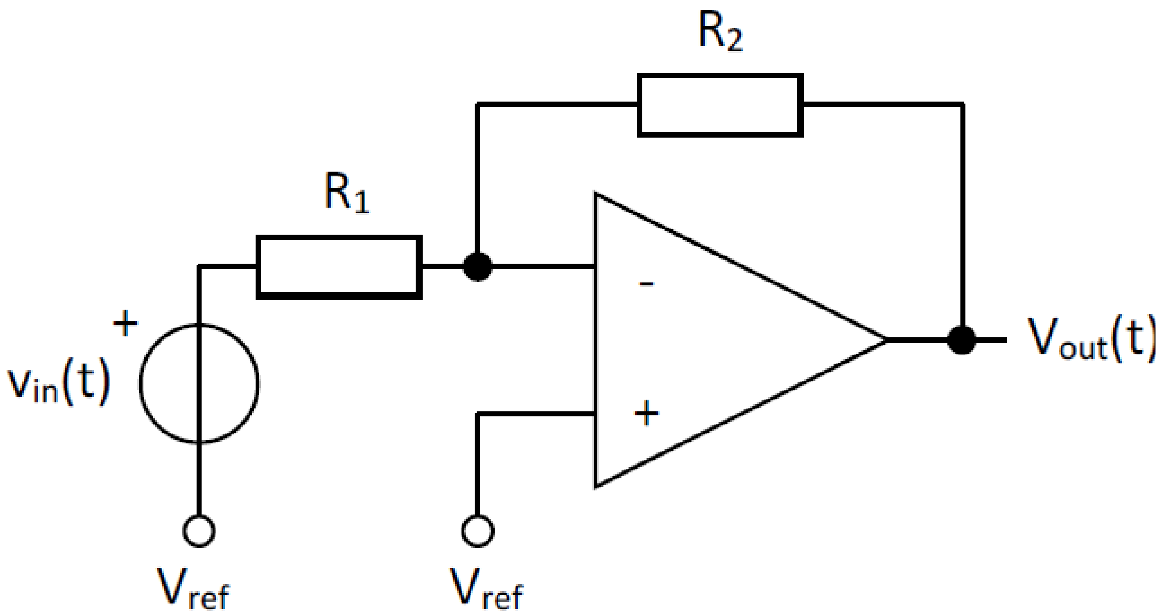
$$v_{out} = A_{VD}.\left(v_{in} - \frac{R_1}{R_1+R_2}.v_{out}\right)$$

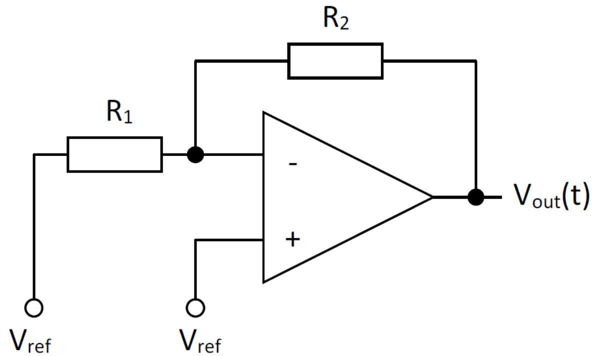




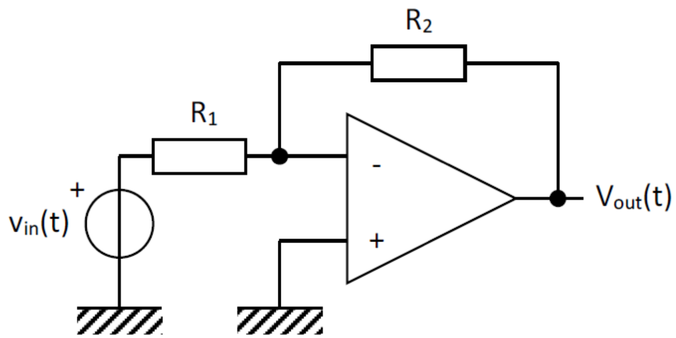


Amplificateur inverseur





En courant continu



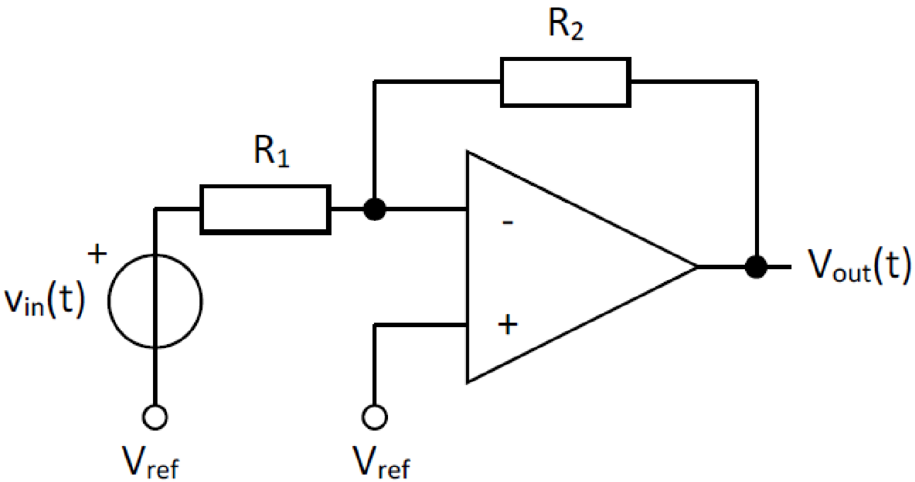
En courant alternatif

$$V_{out}(t) = V_{ref} - \frac{A_0.R_2}{A_0.R_1 + R_1 + R_2} \cdot \frac{1}{1 + \frac{jf}{f_0} \cdot \frac{R_1 + R_2}{A_0.R_1 + R_1 + R_2}} \cdot v_{in}(t)$$

$$K = -\frac{A_0.R_2}{A_0.R_1 + R_1 + R_2} \cong -\frac{R_2}{R_1}$$

$$f_c = f_0 . \frac{A_0.R_1 + R_1 + R_2}{R_1 + R_2}$$

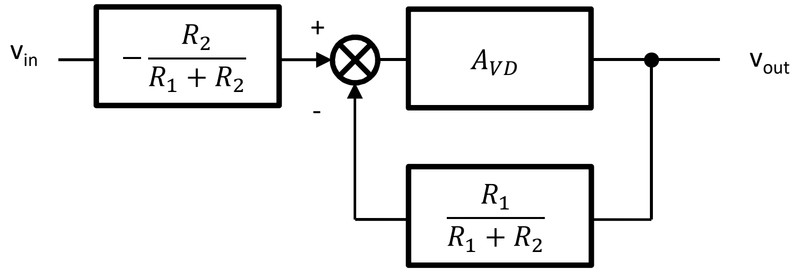
Amplificateur inverseur

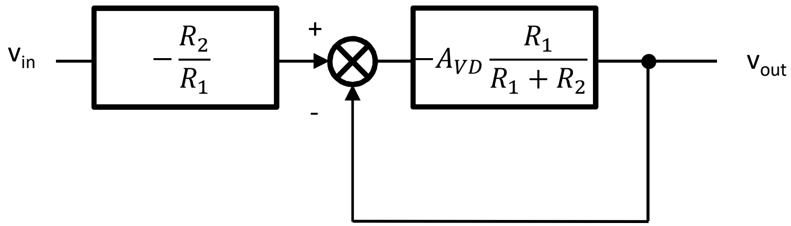


$$= V_{ref} - \frac{A_0 . R_2}{A_0 . R_1 + R_1 + R_2} . \frac{1}{1 + \frac{jf}{f_0} . \frac{R_1 + R_2}{A_0 . R_1 + R_1 + R_2}} . v_{in}(t)$$

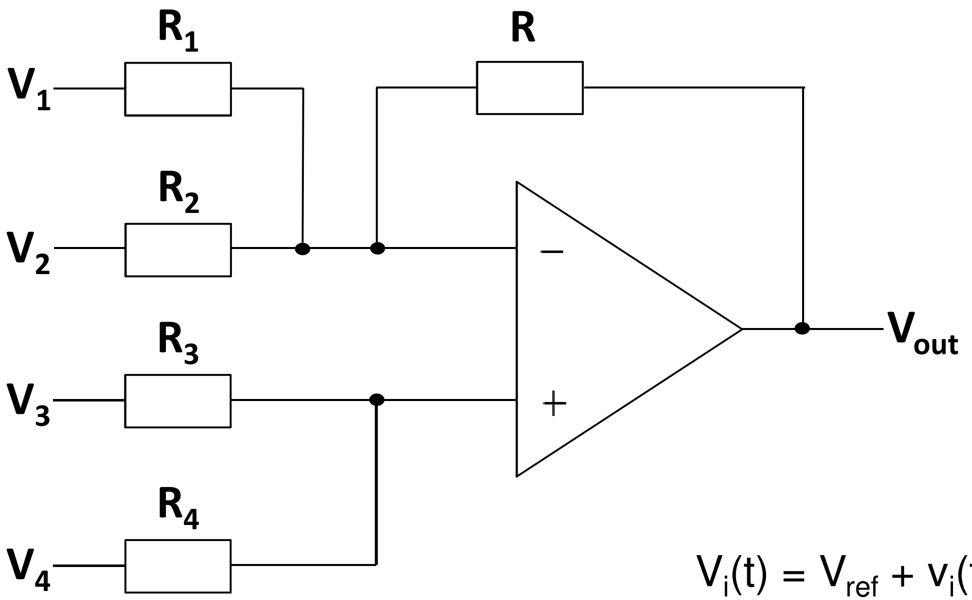
En courant alternatif :

$$v_{out} = A_{VD} . \left(- \frac{R_2}{R_1 + R_2} . v_{in} - \frac{R_1}{R_1 + R_2} . v_{out} \right)$$



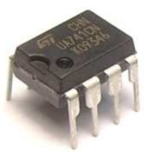


Additionneur / Soustracteur

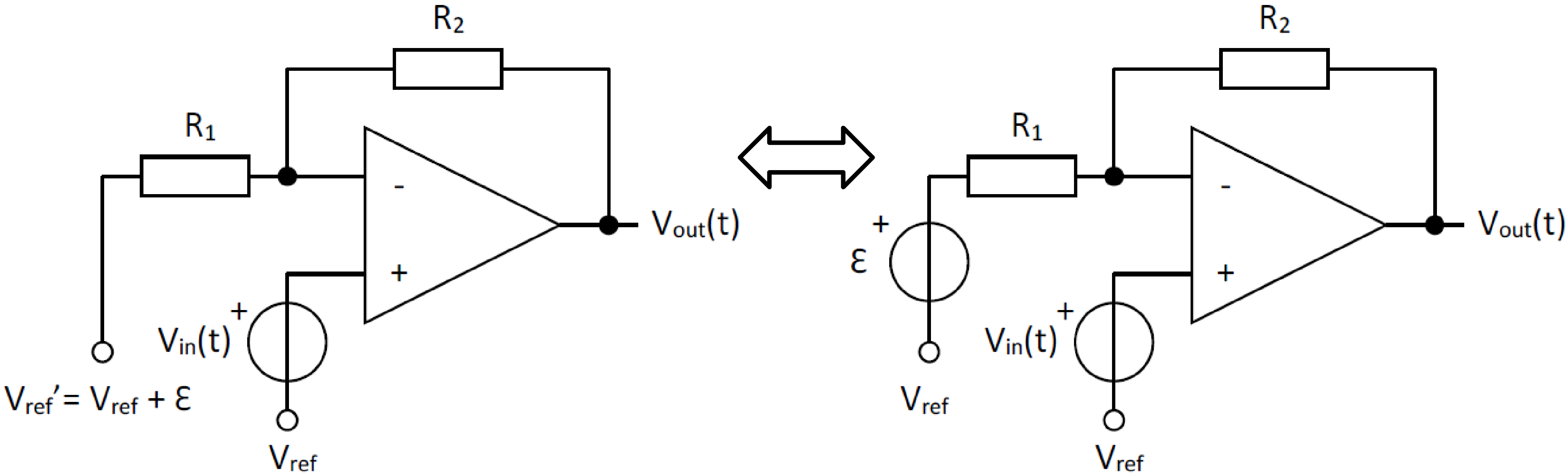


$V_i(t) = V_{ref} + v_i(t)$, pour i = 1 à 4

$$V_{out} = V_{ref} + \left(-\frac{R}{R_1}\right).V_1 + \left(-\frac{R}{R_2}\right).V_2 + \left(\frac{R + R_1//R_2}{R_1//R_2}\right).\frac{(R_4.V_3 + R_3.V_4)}{R_3 + R_4}$$



Tensions de référence différentes

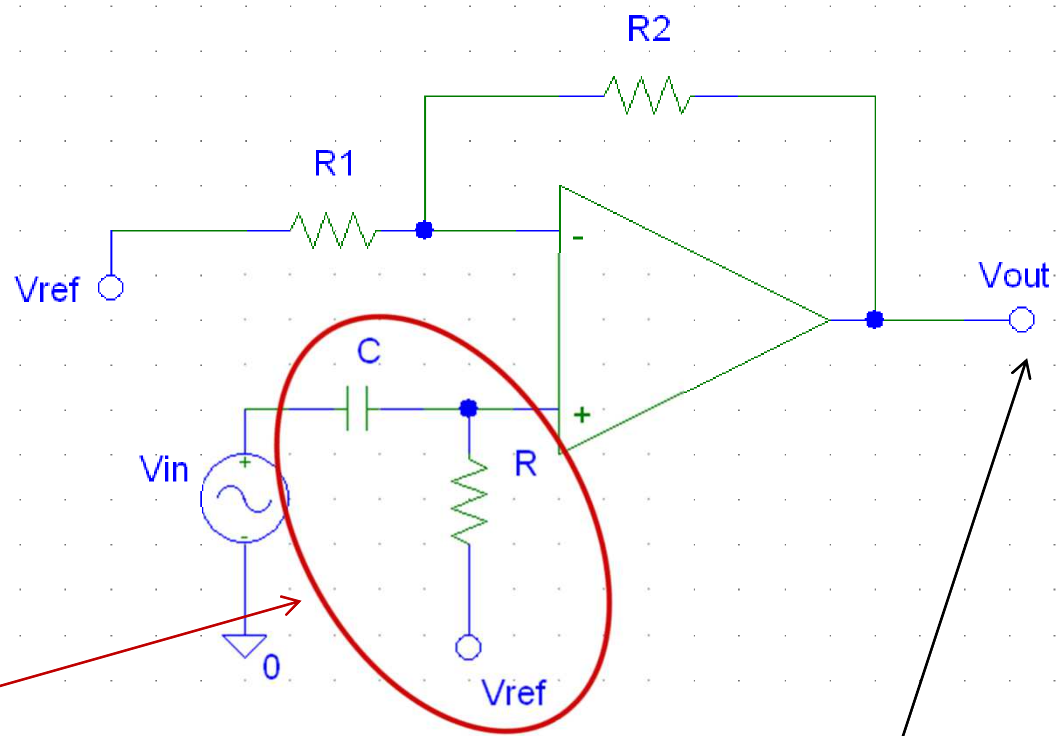


Différentiateur de tension

$$V_{out} = V_{ref} + \left(-\frac{R_2}{R_1}\right).\,\varepsilon + \left(\frac{R_1 + R_2}{R_1}\right).\,v_{in}(t)$$

Changement de tension de référence

- Amplification d'un signal moyenné sur 0V



- Filtre passe-haut de fréquence de coupure $f_c << f_0$
- Elévateur de tension de V_{ref}

Pour récupérer la composante alternative de V_{out} on utilisera un autre filtre passe-haut

Trigger inverseur

- $V_{out} = V_{DD} \rightarrow V^+ > V^-$

$$V^+ = \frac{R_2}{R_1+R_2}.V_{ref} + \frac{R_1}{R_1+R_2}.V_{DD}$$

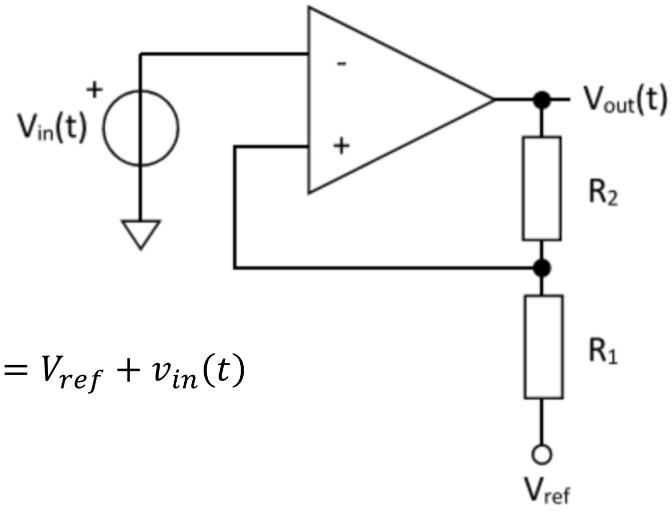
$$= \frac{R_2}{R_1+R_2}.\frac{V_{DD}}{2} + \frac{R_1}{R_1+R_2}.\frac{V_{DD}}{2} + \frac{R_1}{R_1+R_2}.\frac{V_{DD}}{2}$$

$$= \boxed{\frac{V_{DD}}{2} + \frac{R_1}{R_1+R_2}.\frac{V_{DD}}{2}} \quad \boldsymbol{V_T^+}$$

- $V_{out} = 0 \rightarrow V^+ < V^-$

$$V^+ = \frac{R_2}{R_1+R_2}.V_{ref} = \frac{R_2+R_1-R_1}{R_1+R_2}.V_{ref}$$

$$= \boxed{\frac{V_{DD}}{2} - \frac{R_1}{R_1+R_2}.\frac{V_{DD}}{2}} \quad \boldsymbol{V_T^-}$$



$$V_{in}(t) = V_{ref} + v_{in}(t)$$