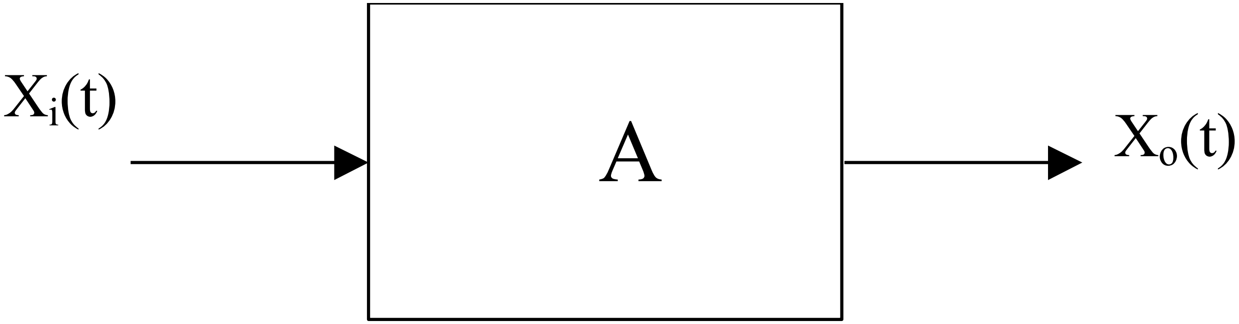
# Capitolul 2

# Aplicatii ale amplificatoarelor operationale

# 2.1. Amplificatoare de semnal

# Amplificatoare liniare



$$X_o(t) = AX_i(t-\tau)$$

$$P_o > P_i$$

## 2.1.1. Parametri

$$Z_i = \frac{v_I}{i_I}$$

$$Z_o = \frac{v_O}{i_O}$$

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

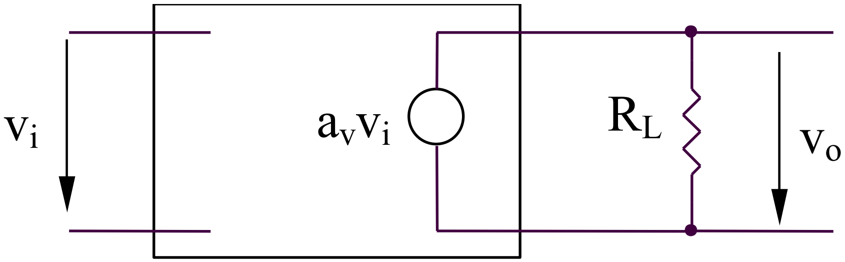
$$A_i = \frac{i_O}{i_I}$$

$$A_z = \frac{v_O}{i_I}$$

$$A_Y = \frac{i_O}{v_I}$$

$$A_p = \frac{P_O}{P_I}$$

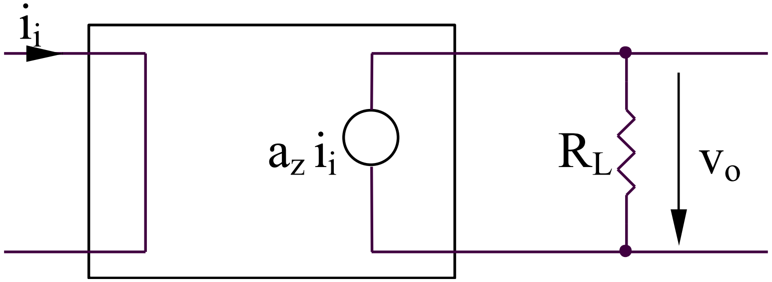
# 2.1.2. Amplificatoare ideale



### Amplificatorul de tensiune

$$v_O = a_v v_I \qquad i_I = 0; P_i = 0$$

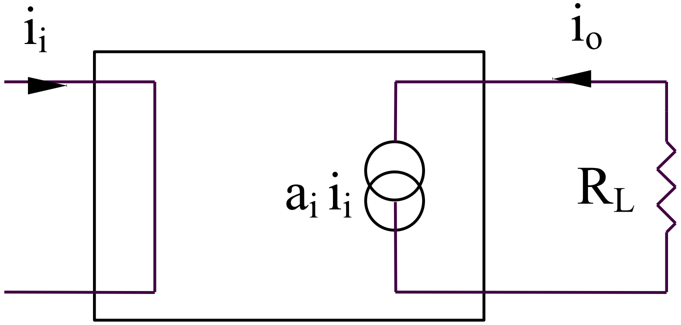
$$R_i \to \infty; R_o = 0$$



### Amplificatorul trans-impedanta

$$v_O = a_z i_I \qquad v_I = 0; P_i = 0$$

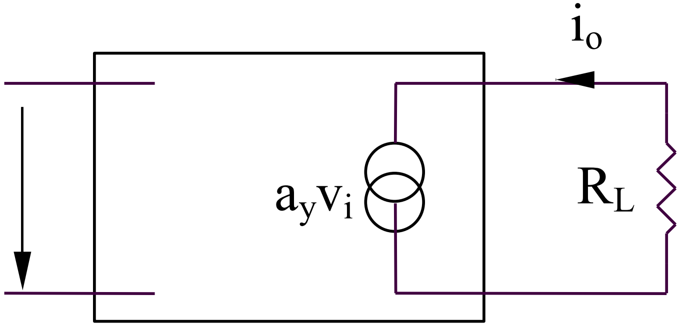
$$R_i = 0; R_o = 0$$



### Amplificatorul de curent

$$i_O = a_i i_I \qquad v_I = 0; P_i = 0$$

$$R_i = 0; R_o \to \infty$$

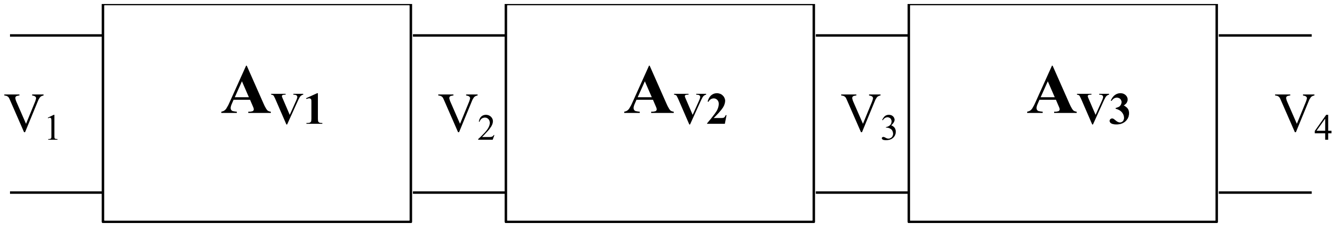


### Amplificatorul trans-admitanta

$$i_O = a_y v_I \qquad i_I = 0; P_i = 0$$

$$R_i \to \infty; R_o \to \infty$$

# 2.1.3. Cuplarea amplificatoarelor



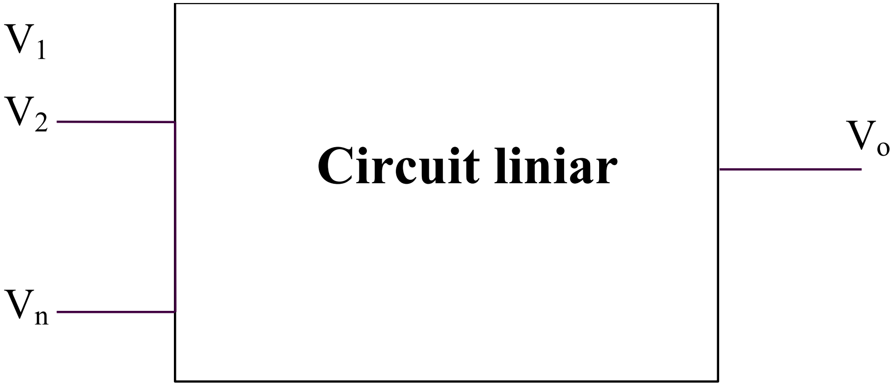
$$A_V = \frac{V_4}{V_1} = A_{V1} A_{V2} A_{V3}$$

$$A_V(dB) = A_{V1}(dB) + A_{V2}(dB) + A_{V3}(dB)$$

# 2.2. Aplicatii ale amplificatoarelor operationale

# 2.2. Aplicatii ale amplificatoarelor operationale

## Teorema superpozitiei



$V_1$

$V_2$

$V_n$

**Circuit liniar**

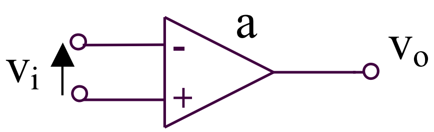
$V_o$

$$V_o = V_o\Big|_{\substack{V_1 \neq 0 \\ V_2 = V_3 = \dots V_n = 0}} + V_o\Big|_{\substack{V_2 \neq 0 \\ V_1 = V_3 = \dots V_n = 0}} + \dots + V_o\Big|_{\substack{V_n \neq 0 \\ V_1 = V_2 = \dots V_{n-1} = 0}}$$

# 2.2. Aplicatii ale amplificatoarelor operationale

Un amplificator operational ideal este caracterizat prin:

- amplificare in tensiune infinita
- impedanta de intrare infinita
- impedanta de iesire nula



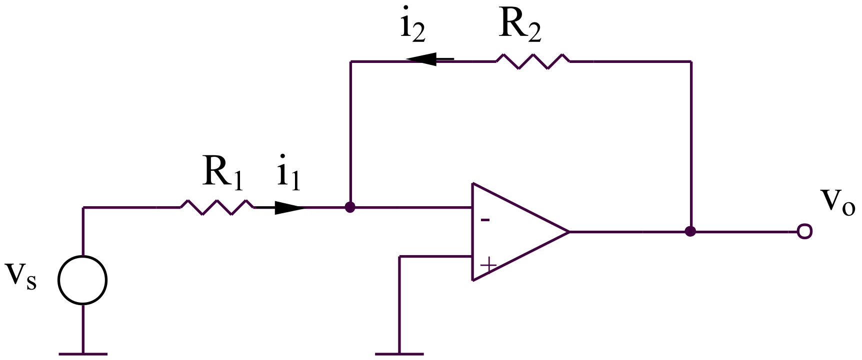
$$a \to \infty$$

$$v_i \to 0$$

In consecinta:

- tensiunea intre cele doua intrari este zero
- curentii de intrare sunt zero

## 2.2.1. Amplificatorul inversor



$$i_1 = -i_2$$

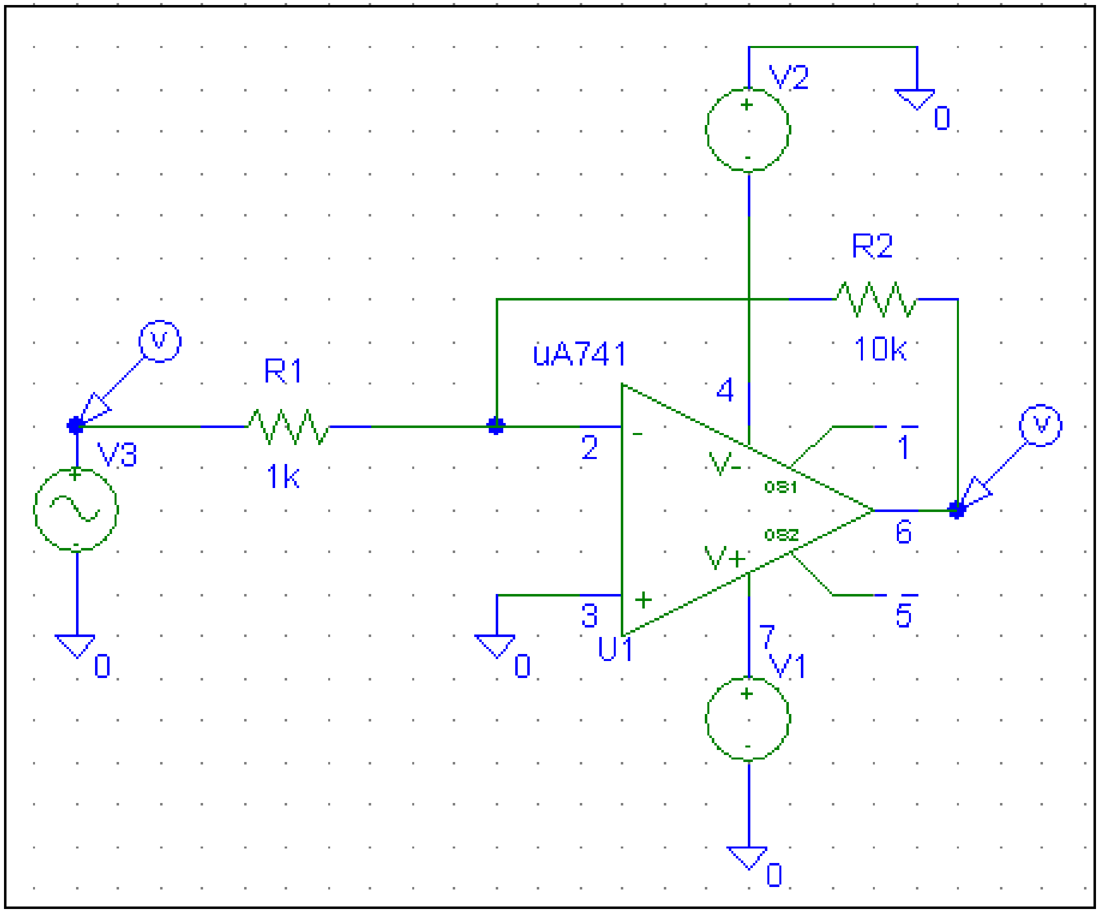
$$\frac{v_s}{R_1} = -\frac{v_o}{R_2}$$

$$\Rightarrow A = \frac{v_o}{v_s} = -\frac{R_2}{R_1}$$

# SIMULARI pentru amplificatorul inversor

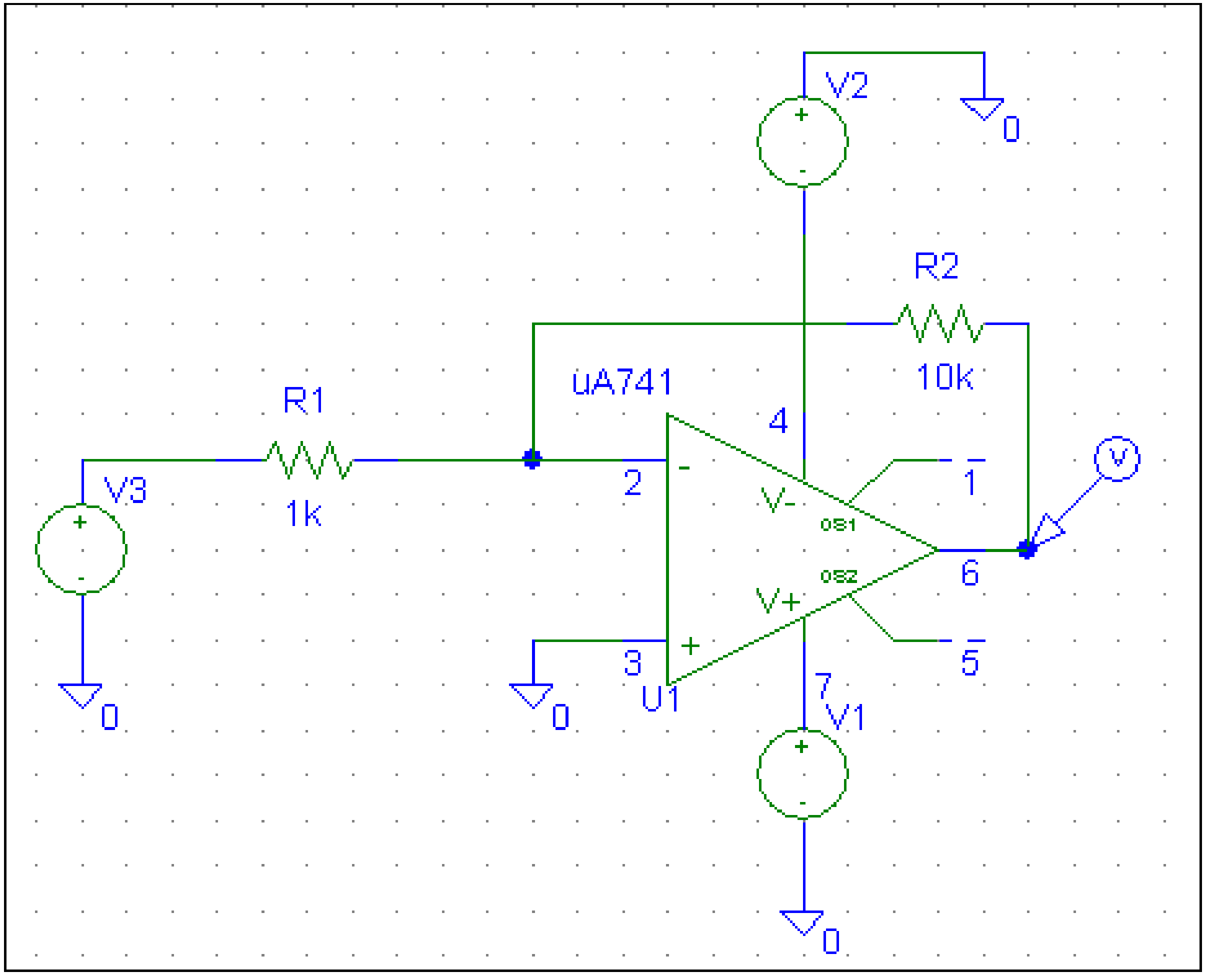
# SIMULARI pentru amplificatorul inversor

## SIM 2.1: $v_3$ (t), $v_O$ (t)

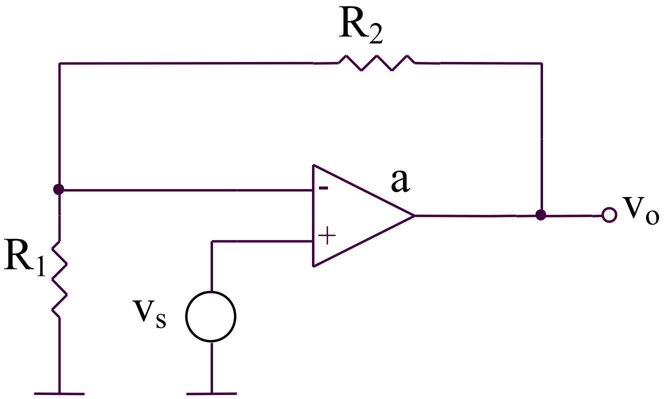


# SIMULARI pentru amplificatorul inversor

## SIM 2.2: $v_O$ ($v_3$)



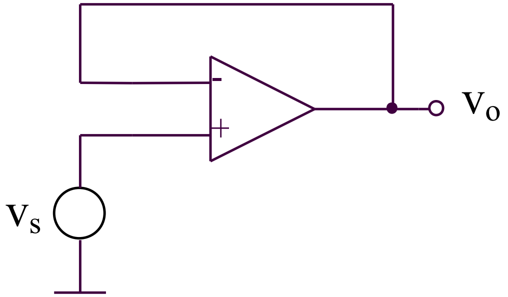
## 2.2.2. Amplificatorul neinversor



$$v_s = v_o \frac{R_1}{R_1 + R_2} \Rightarrow$$

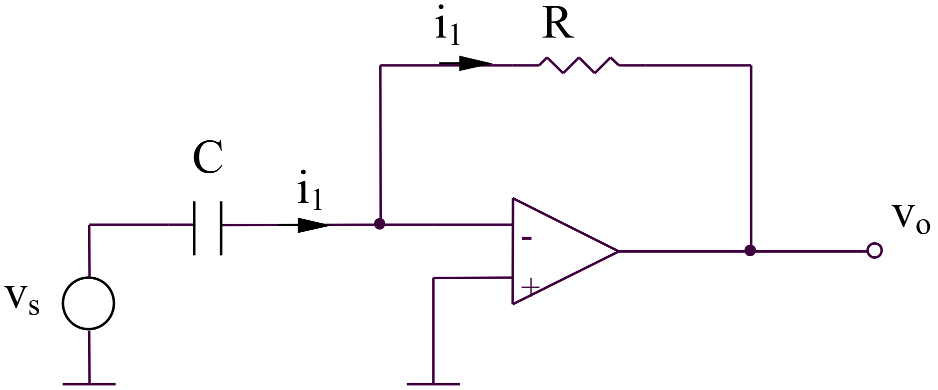
$$A = \frac{v_o}{v_s} = 1 + \frac{R_2}{R_1}$$

## 2.2.3. Circuitul repetor



$$v_O = v_s$$

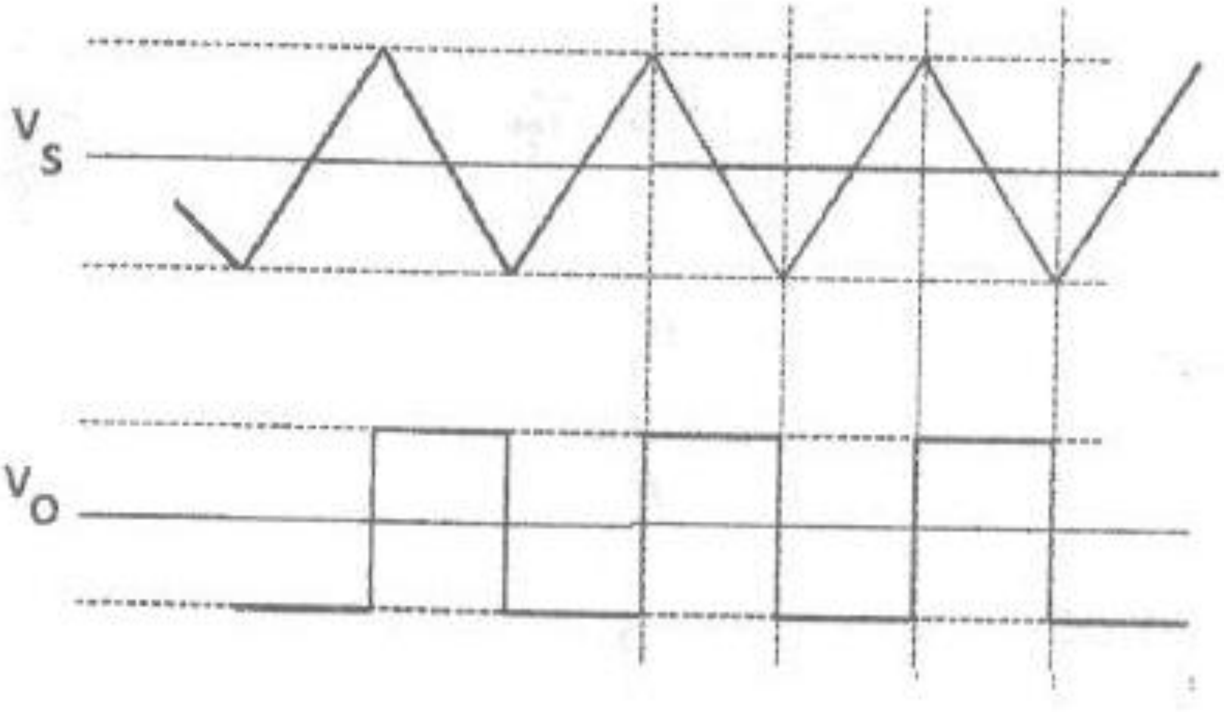
# 2.2.4. Circuitul de derivare



$$i_1 = C\frac{dv_s}{dt}$$

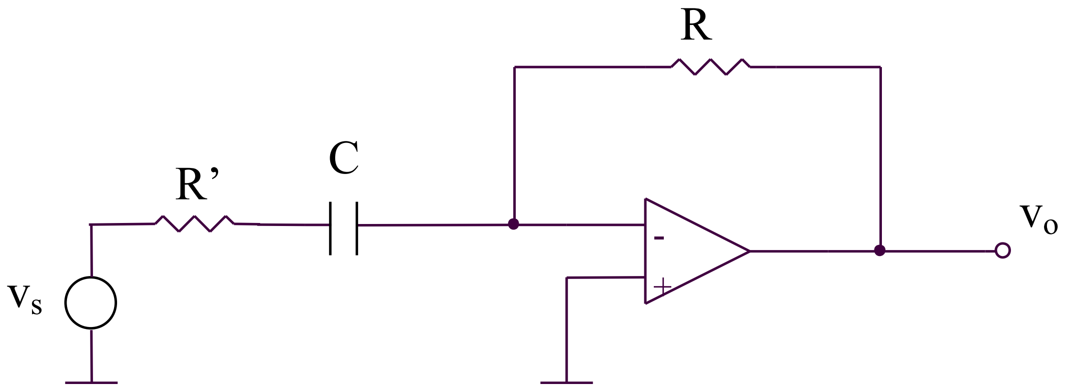
$$v_o = -Ri_1 = -RC\frac{dv_s}{dt}$$

## 2.2.4. Circuitul de derivare

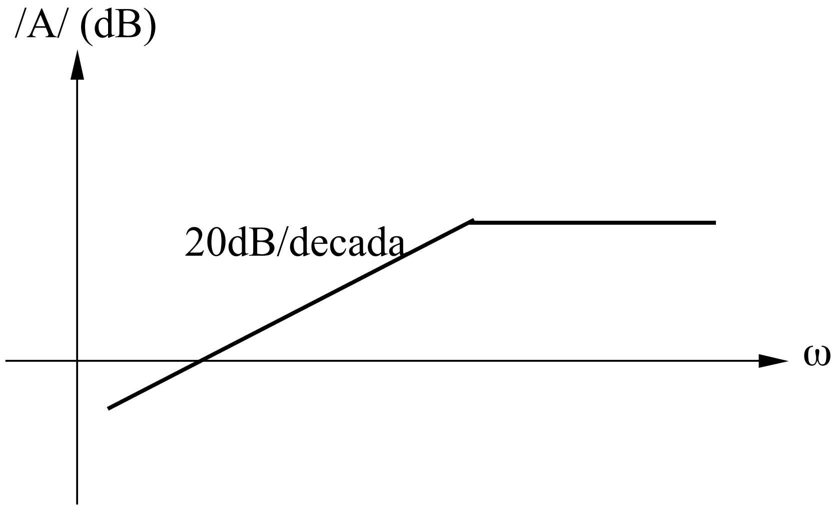


# 2.2.4. Circuitul de derivare

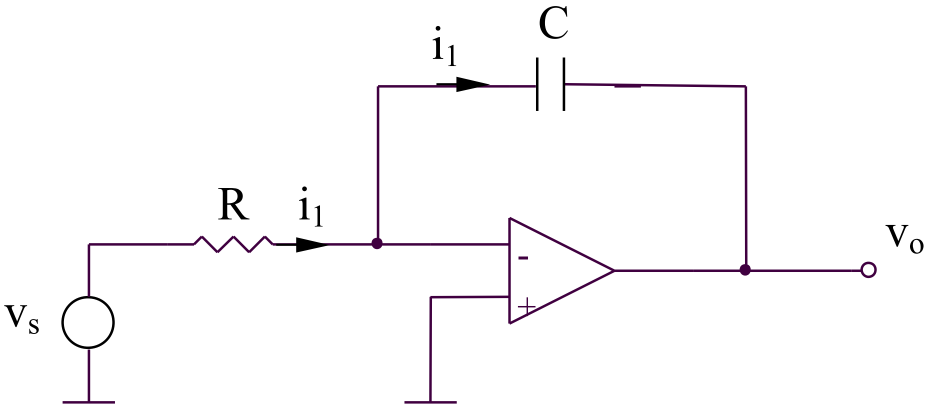
Introducerea R' – pentru cresterea stabilitatii



$$A(j\omega) = -\frac{R}{R' + \frac{1}{j\omega C}} = -\frac{R}{R'}\frac{j\omega R' C}{1 + j\omega R' C}$$



# 2.2.5. Circuitul de integrare

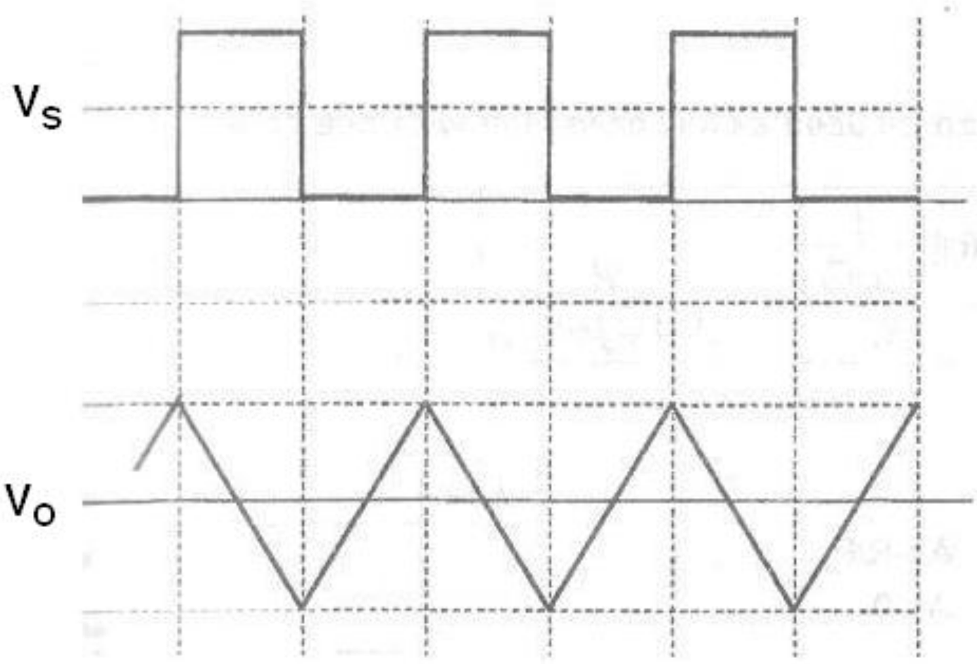


$$i_1 = \frac{v_s(t)}{R}$$

$$v_o = -\frac{1}{C}\int i_1(t)dt + v_o(0)$$

$$v_o = -\frac{1}{RC}\int v_s(t)dt + v_o(0)$$

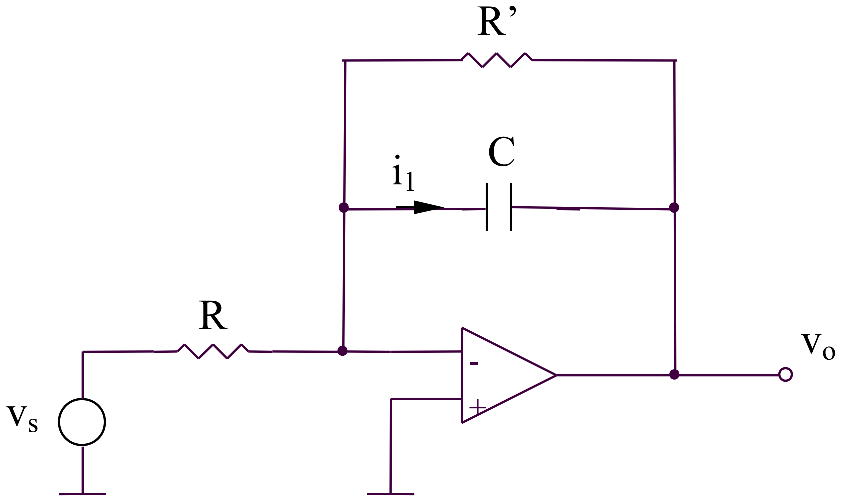
## 2.2.5. Circuitul de integrare



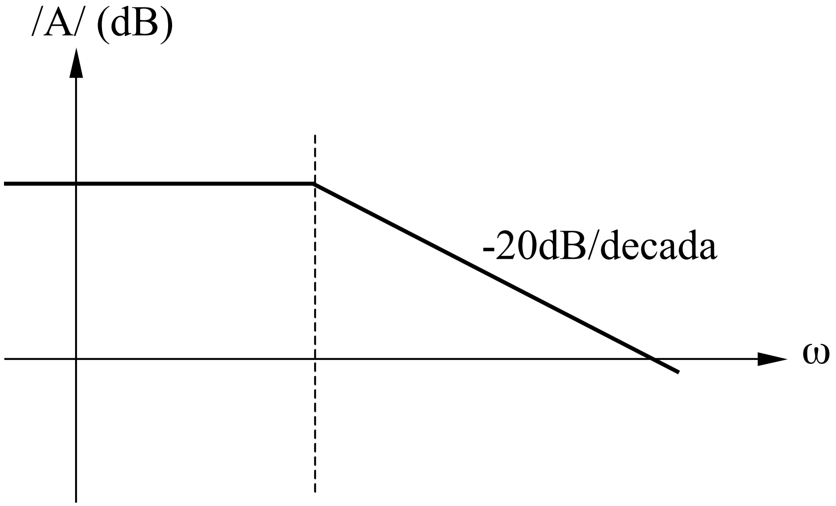
# 2.2.5. Circuitul de integrare

Introducerea R' – pentru evitarea saturarii in curent continuu a AO

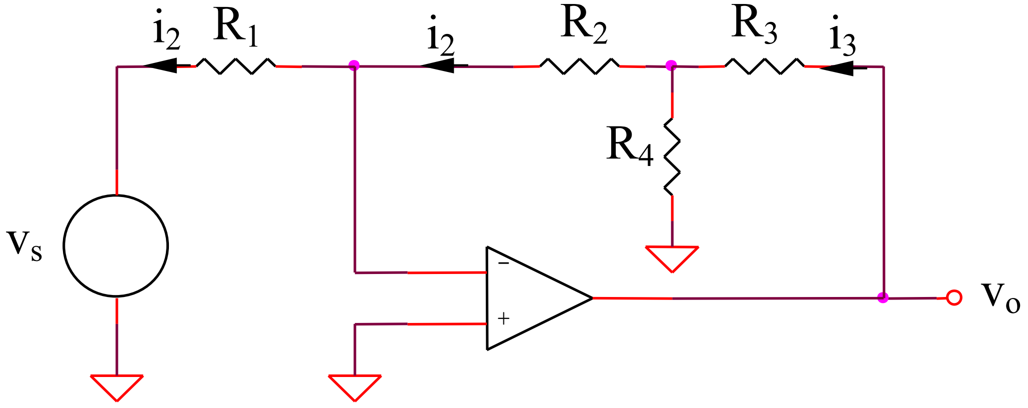
Amplificarea in curent continuu finita, Acc = - R'/R



$$A(j\omega) = -\frac{R' // \left(\frac{1}{j\omega C}\right)}{R} = -\frac{R'}{R(1 + j\omega R' C)}$$



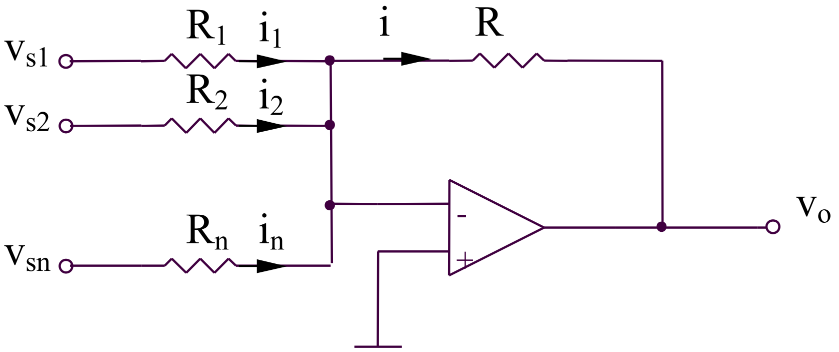
# 2.2.6. Circuit cu amplificare marita



$$A = \frac{v_o}{v_s} = \frac{v_o}{i_3}\frac{i_3}{i_2}\frac{i_2}{v_s}$$

$$A = -\frac{R_2R_3 + R_2R_4 + R_3R_4}{R_1R_4}$$

# 2.2.7. Sumatorul inversor



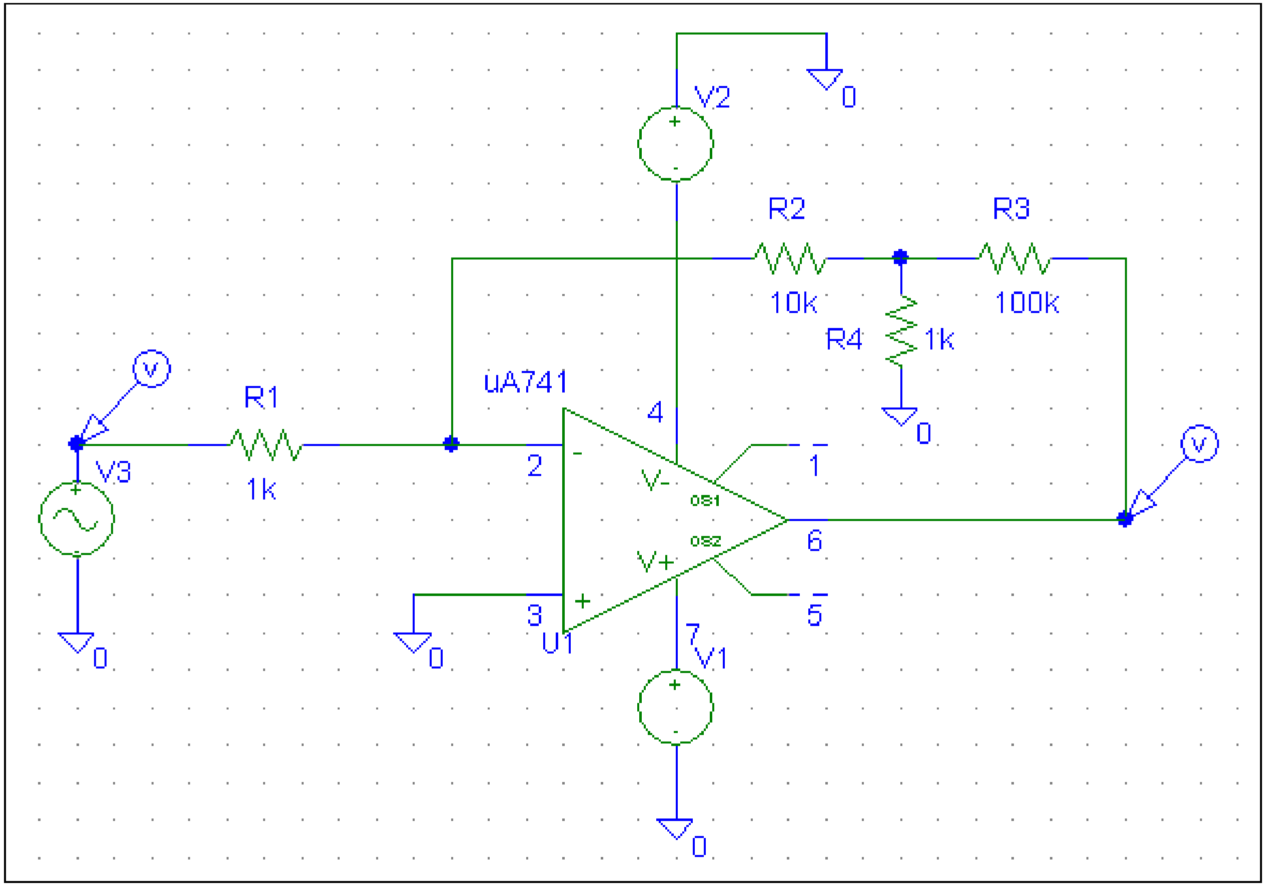
$$i = \sum_{i=1}^{n} i_i = \sum_{i=1}^{n} \frac{v_{si}}{R_i}$$

$$v_o = -Ri = -R\sum_{i=1}^{n} \frac{v_{si}}{R_i}$$

# SIMULARI pentru circuitul cu amplificare marita

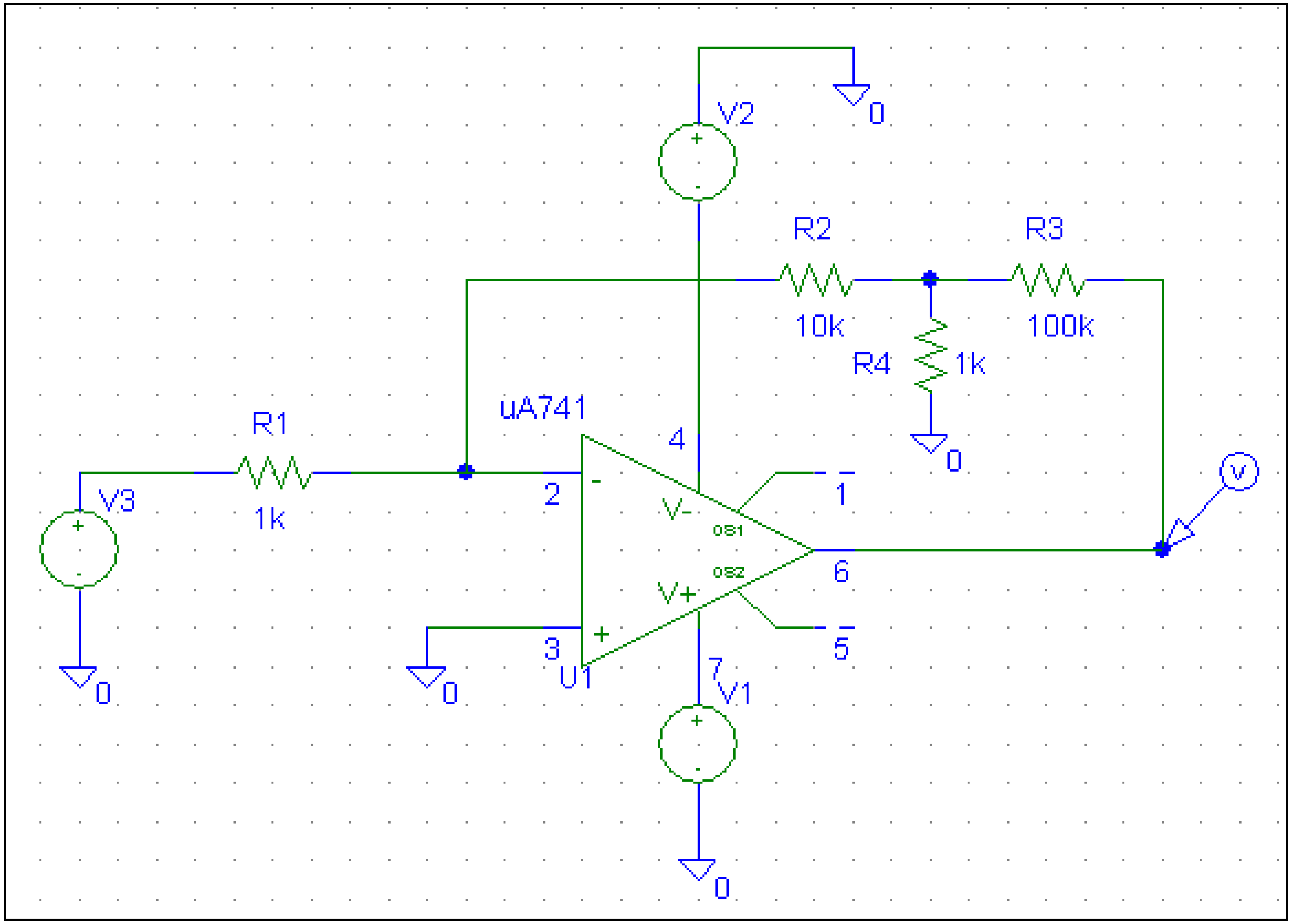
# SIMULARI pentru circuitul cu amplificare marita

## SIM 2.3: $v_3$ (t), $v_O$ (t)



# SIMULARI pentru circuitul cu amplificare marita

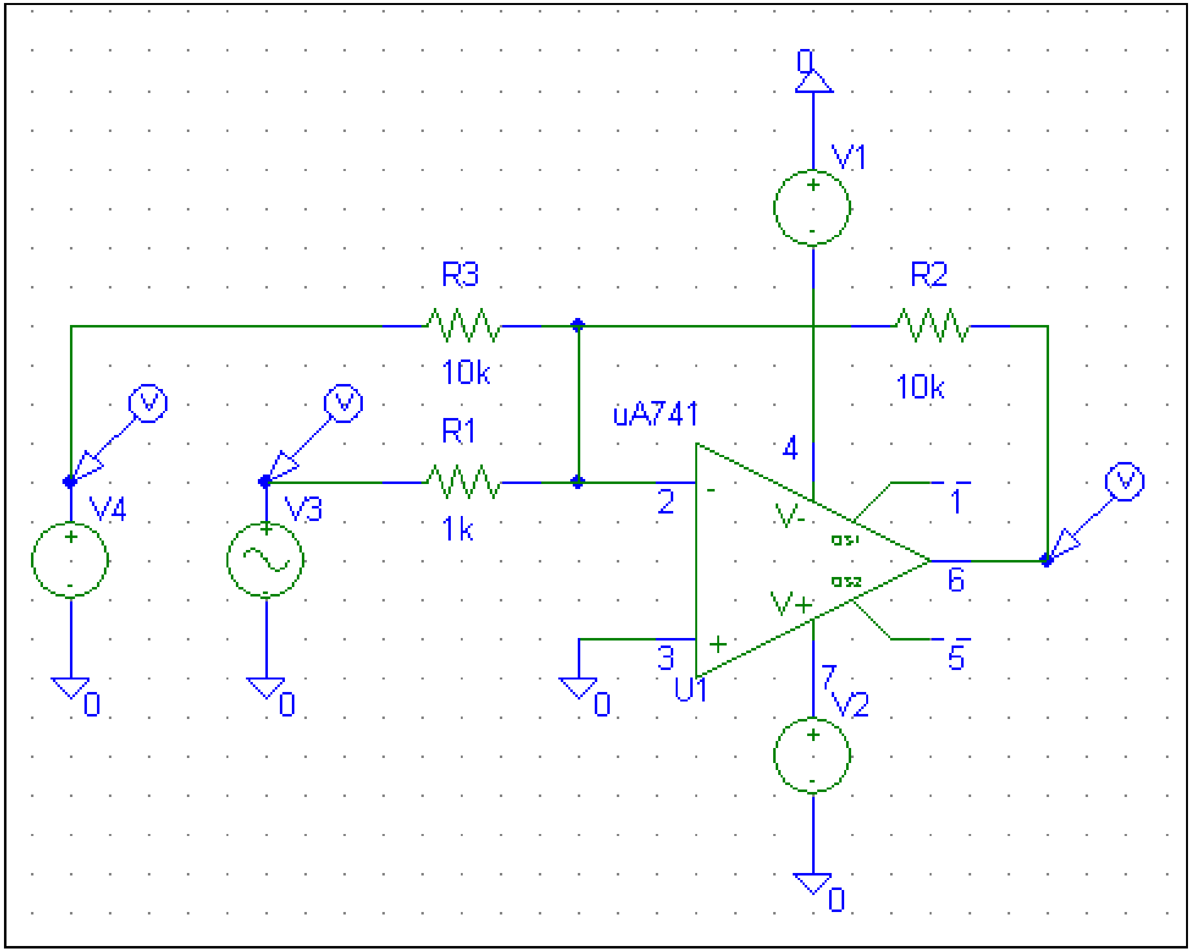
## SIM 2.4: $v_O$ ($v_3$)



# SIMULARI pentru sumatorul inversor

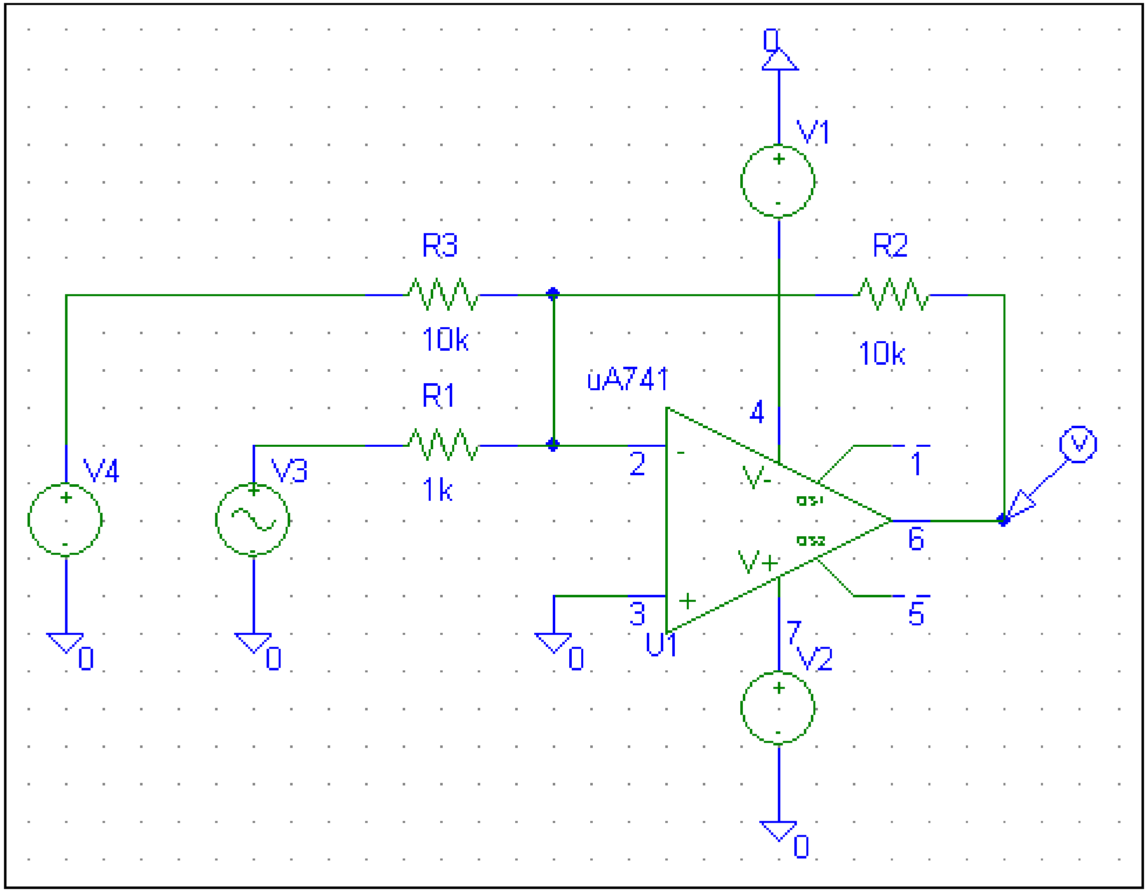
# SIMULARI pentru sumatorul inversor

## SIM 2.5: $v_3$ (t), $v_4$ (t), $v_O$ (t)

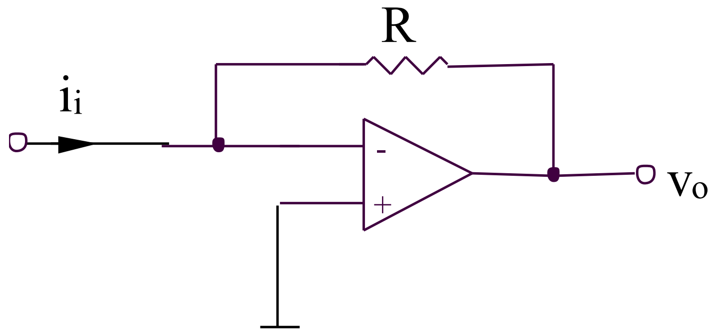


# SIMULARI pentru sumatorul inversor

## SIM 2.6: $v_O$ (t), $v_4$ - parametru

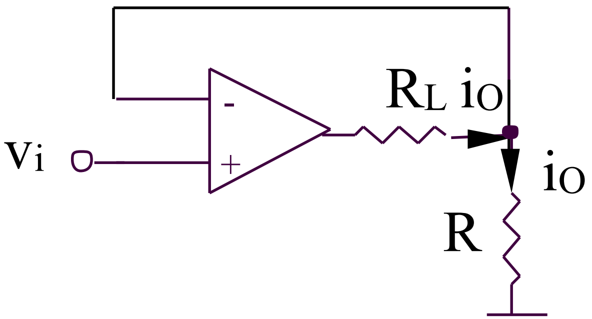


## 2.2.8. Convertorul curent-tensiune



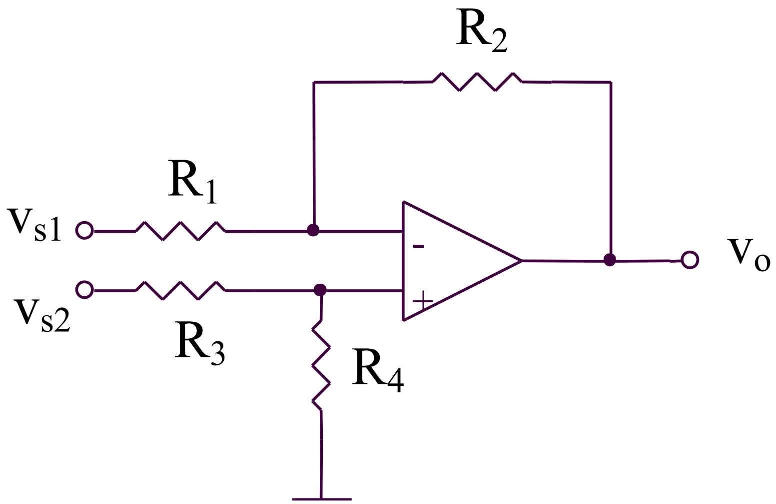
$$v_O = -Ri_i$$

## 2.2.9. Convertorul tensiune-curent



$$i_O = v_i / R$$

# 2.2.10. Circuitul de diferenta (1)



$$v_o = v_{s1}\left(-\frac{R_2}{R_1}\right) + v_{s2}\frac{R_4}{R_3 + R_4}\left(1 + \frac{R_2}{R_1}\right)$$

Pentru obtinerea:

$$v_o = A(v_{s2} - v_{s1})$$

este necesara conditia:

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

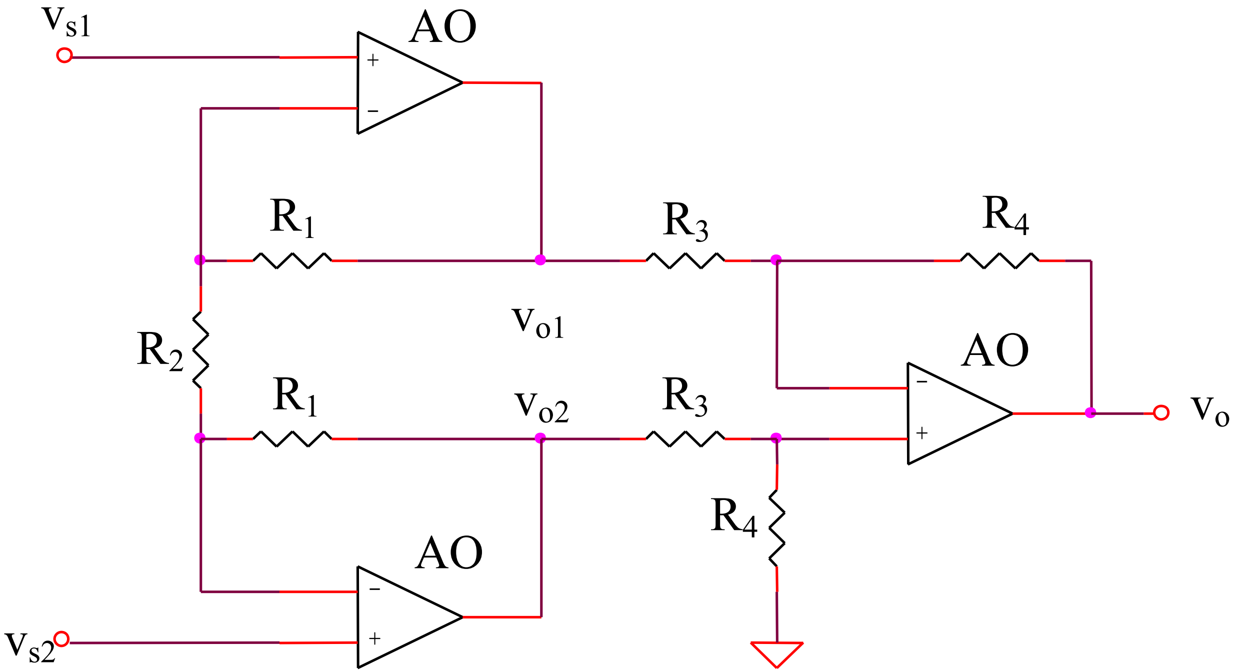
echivalenta cu:

$$R_1 R_4 = R_2 R_3$$

rezultand:

$$v_o = \frac{R_2}{R_1}(v_{s2} - v_{s1})$$

# 2.2.11. Circuitul de diferenta (2)

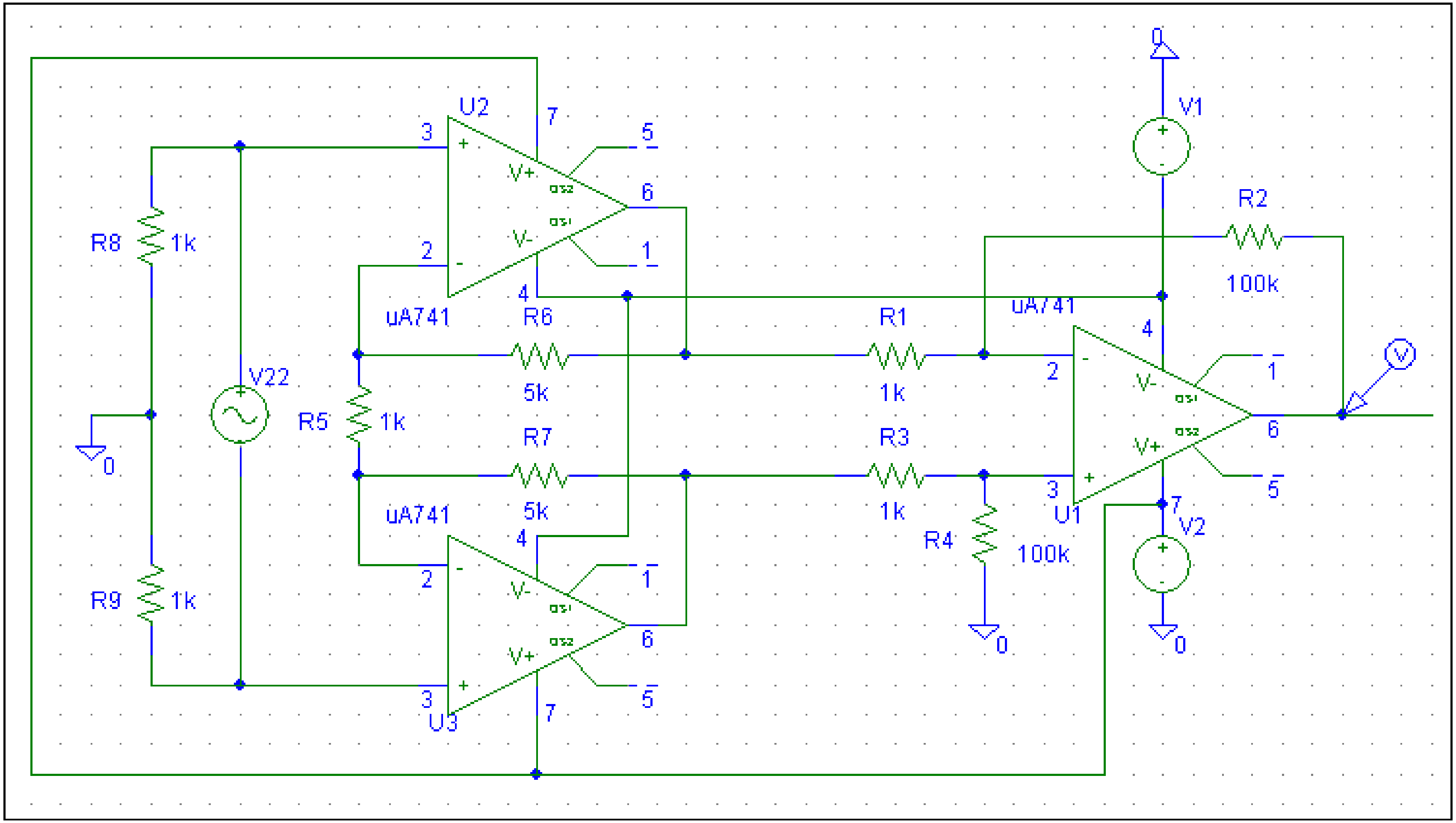


$$\left.\begin{aligned} v_{o1} &= v_{s1}\left(1+\frac{R_1}{R_2}\right) - v_{s2}\frac{R_1}{R_2} \\ v_{o2} &= v_{s2}\left(1+\frac{R_1}{R_2}\right) - v_{s1}\frac{R_1}{R_2} \\ v_o &= \frac{R_4}{R_3}\left(v_{o2}-v_{o1}\right) \end{aligned}\right\} \Rightarrow A = \frac{v_o}{v_{s2}-v_{s1}} = \left(1+2\frac{R_1}{R_2}\right)\frac{R_4}{R_3}$$

# SIMULARI pentru circuitul de diferenta (2)

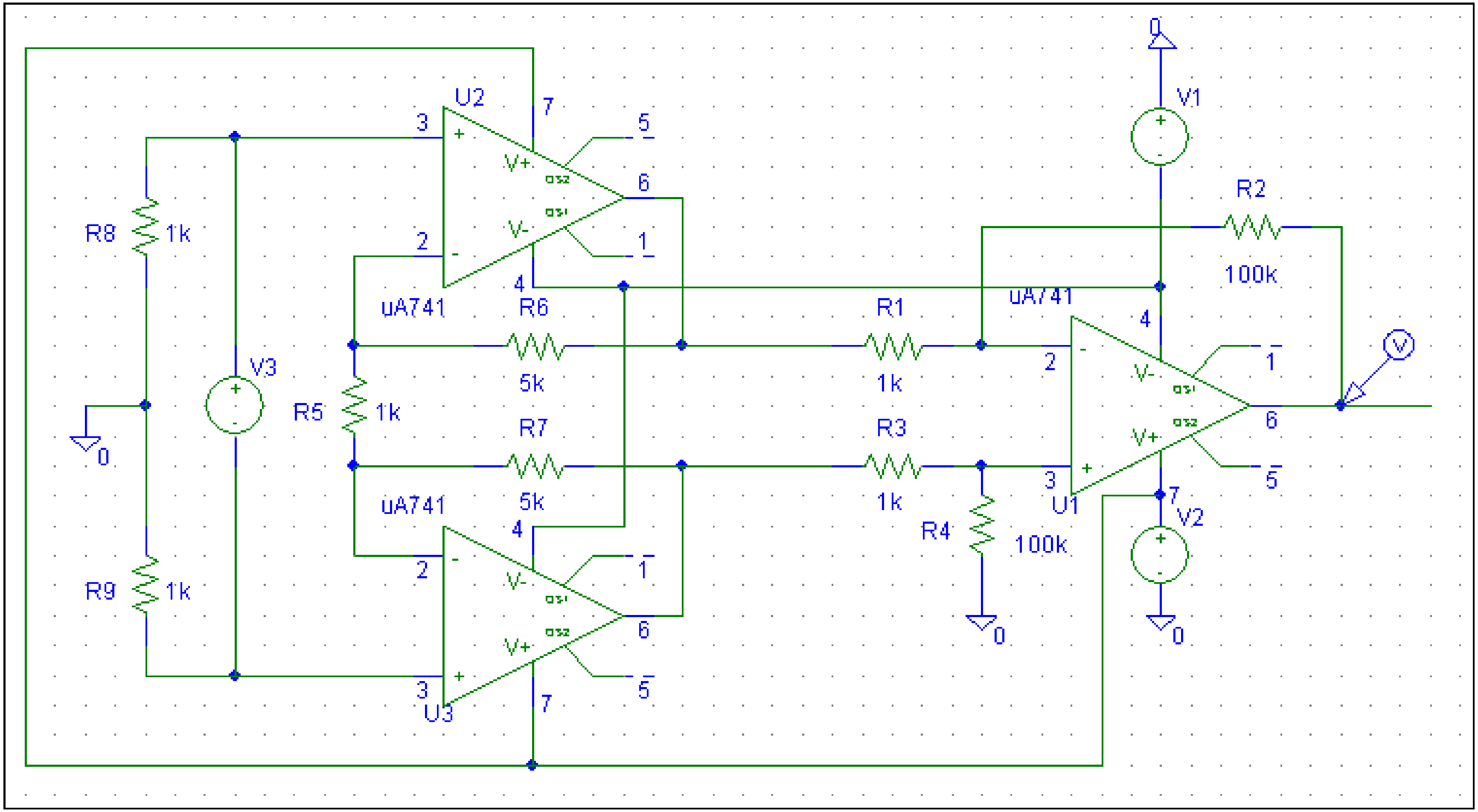
# SIMULARI pentru circuitul de diferenta (2)

## SIM 2.7: $v_O$ (t)

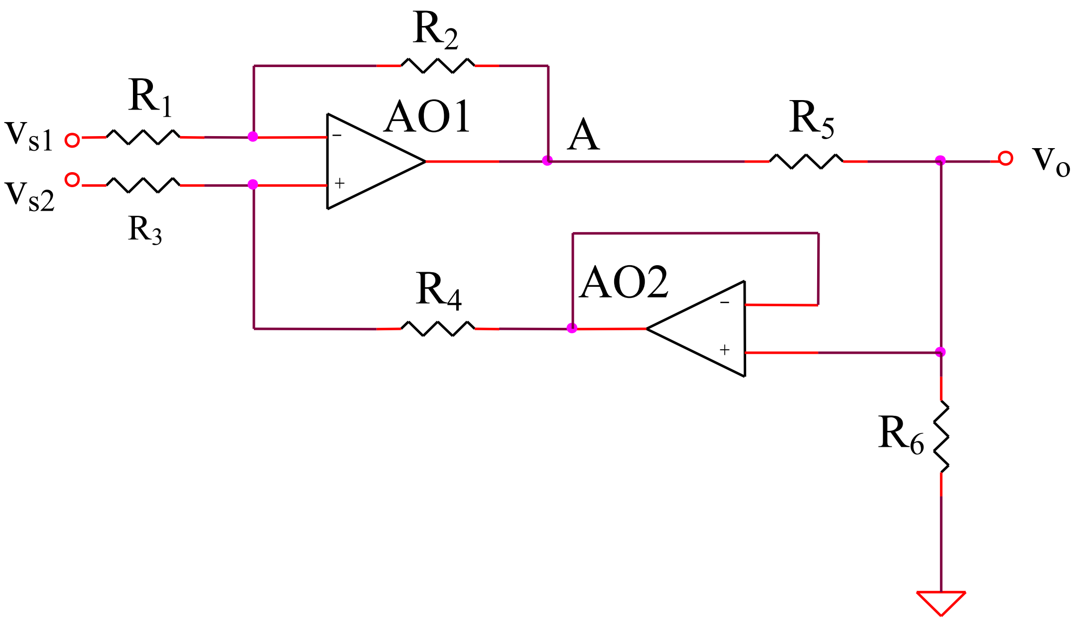


# SIMULARI pentru circuitul de diferenta (2)

## SIM 2.8: $v_O$ ($v_3$)



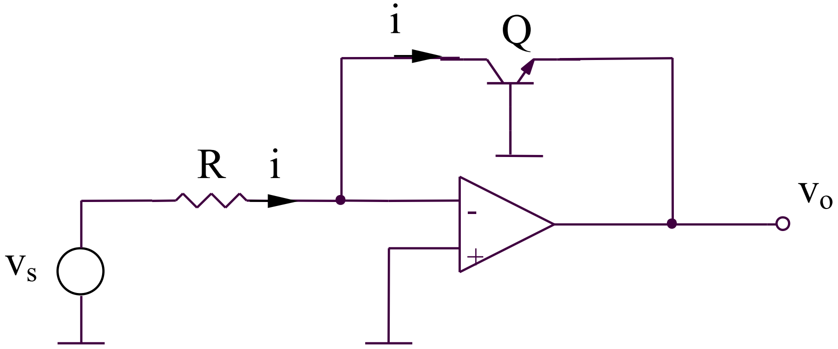
# 2.2.12. Circuitul de diferenta (3)



$$\left.\begin{aligned} v_A &= v_{s1}\left(-\frac{R_2}{R_1}\right)+\frac{v_{s2}R_4+v_oR_3}{R_3+R_4}\left(1+\frac{R_2}{R_1}\right) \\ v_o &= v_A\frac{R_6}{R_5+R_6} \end{aligned}\right\} \Rightarrow \left.\begin{aligned} v_o\left[\left(1+\frac{R_5}{R_6}\right)-\frac{1+\dfrac{R_2}{R_1}}{1+\dfrac{R_4}{R_3}}\right] &= v_{s2}\frac{1+\dfrac{R_2}{R_1}}{1+\dfrac{R_3}{R_4}}-v_{s1}\frac{R_2}{R_1} \\ v_o &= A\left(v_{s2}-v_{s1}\right) \end{aligned}\right\} \Rightarrow$$

$$\Rightarrow R_1R_4 = R_2R_3 \Rightarrow A = \frac{v_o}{v_{s2}-v_{s1}} = \frac{R_6R_2}{R_5R_1}$$

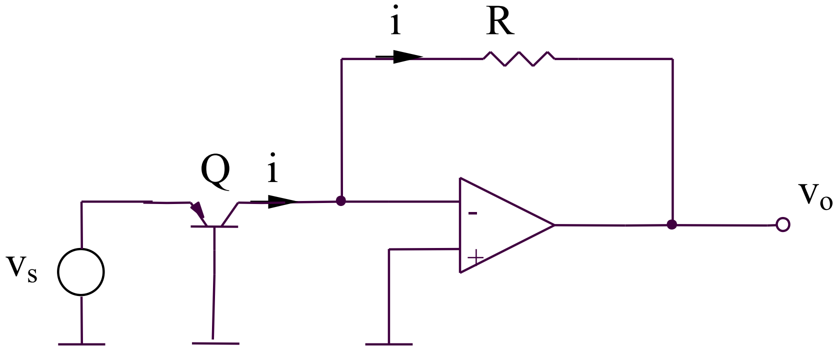
# 2.2.13. Convertoarele logaritmic si anti-logaritmic



**Convertorul logaritmic**

$$v_o = -v_{BE} = -V_{th}\ln\left(\frac{i}{I_S}\right)$$

$$v_o = -V_{th}\ln\left(\frac{v_s}{RI_S}\right)$$



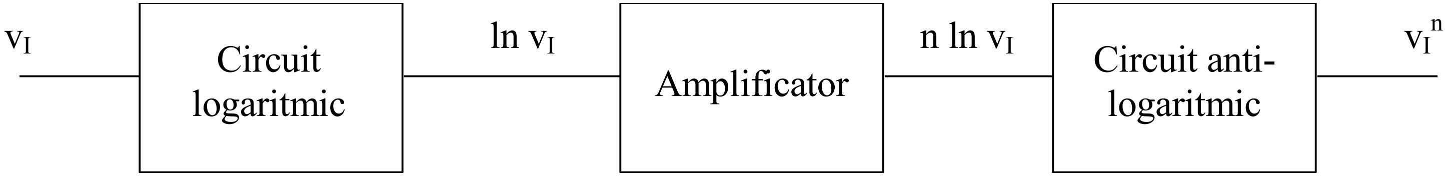
**Convertorul anti-logaritmic**

$$v_o = -iR$$

$$i = I_S e^{\frac{v_{EB}}{V_{th}}} = I_S e^{\frac{v_S}{V_{th}}}$$

# 2.2.14. Circuit pentru calculul functiei Y = X$^n$

$$X^n = e^{n\ln x}$$



$v_I$

Circuit logaritmic

$\ln v_I$

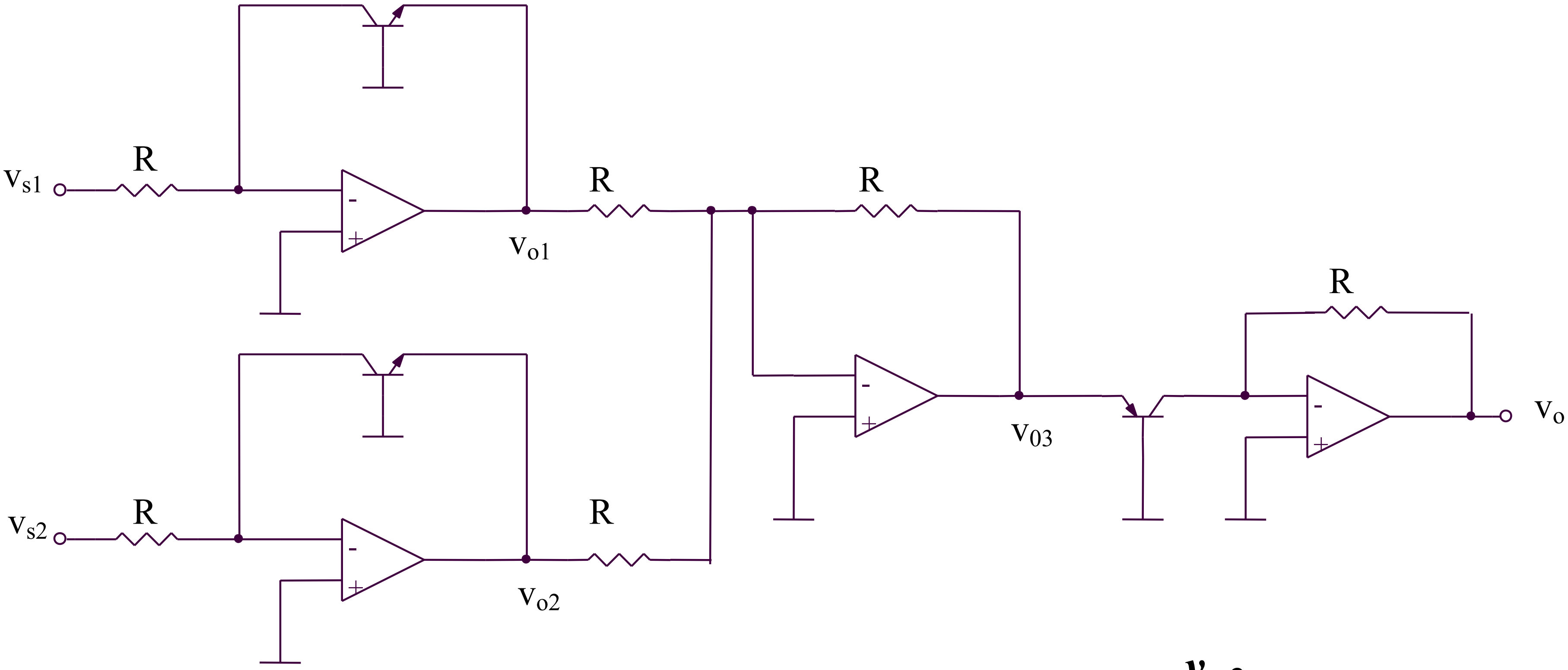
Amplificator

$n \ln v_I$

Circuit anti-logaritmic

$v_I^{\,n}$

# 2.2.15. Circuit de multiplicare



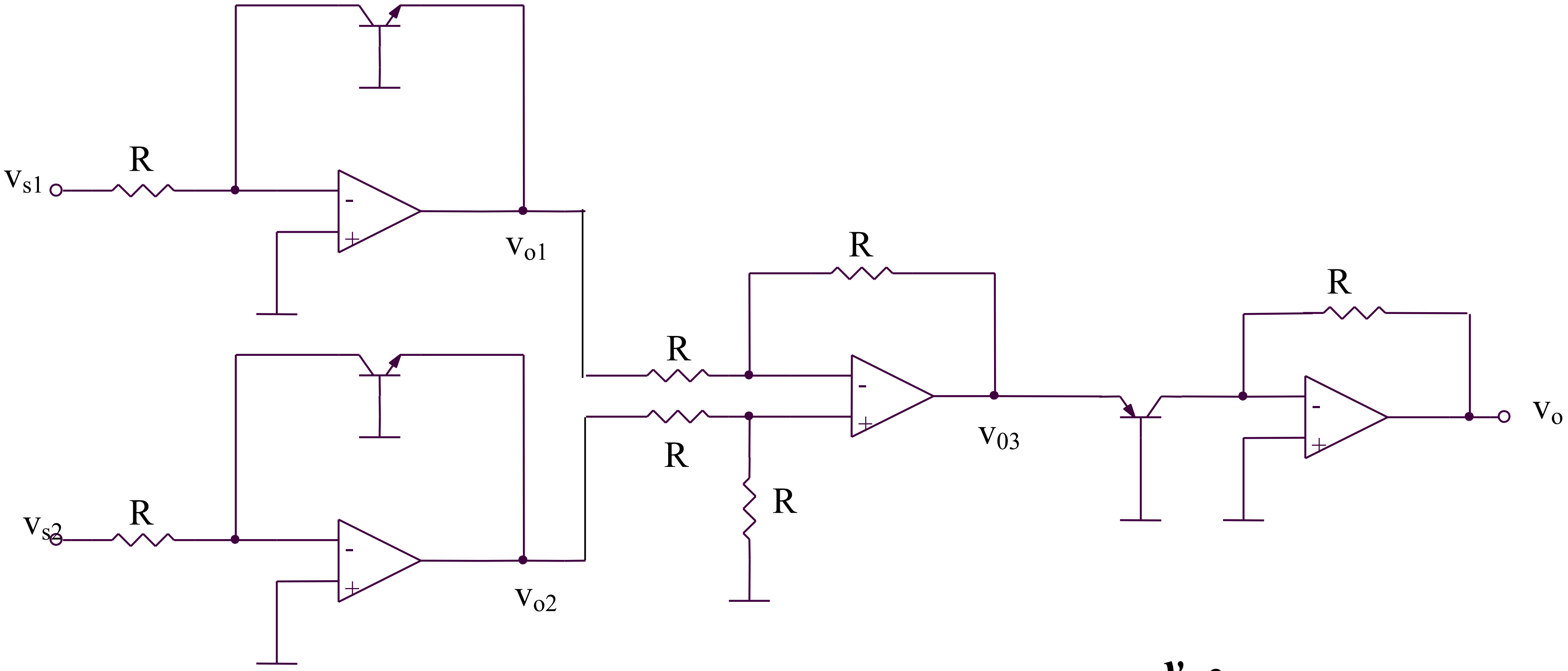
$$v_{o1} = -V_{th} \ln \frac{v_{s1}}{RI_S}$$

$$v_{o2} = -V_{th} \ln \frac{v_{s2}}{RI_S}$$

$$v_{o3} = \left(-\frac{R}{R}\right)v_{o1} + \left(-\frac{R}{R}\right)v_{o2} = -\left(v_{o1} + v_{o2}\right) = V_{th} \ln \frac{v_{s1}v_{s2}}{R^2 I_S^2}$$

$$v_o = -RI_S e^{\frac{v_{o3}}{V_{th}}} = -\frac{v_{s1}v_{s2}}{RI_S}$$

# 2.2.16. Circuit de impartire

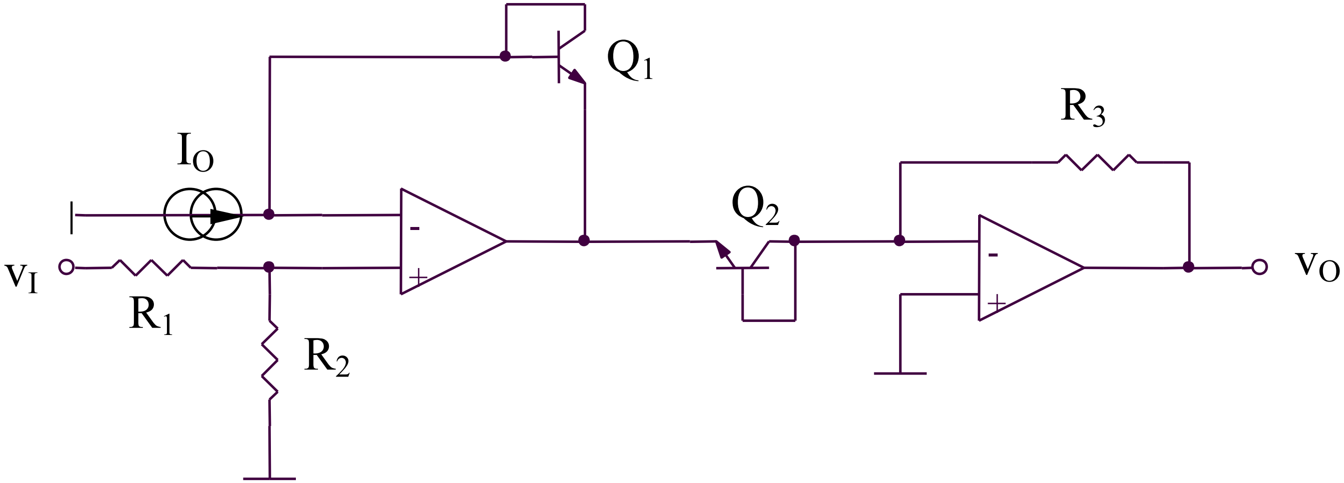


$$v_{o1} = -V_{th} \ln \frac{v_{s1}}{RI_S} \qquad v_{o2} = -V_{th} \ln \frac{v_{s2}}{RI_S}$$

$$v_{o3} = v_{o2} - v_{o1} = V_{th}\, ln \frac{v_{s1}}{v_{s2}}$$

$$v_o = -RI_S e^{\frac{v_{o3}}{V_{th}}} = -RI_S \frac{v_{s1}}{v_{s2}}$$

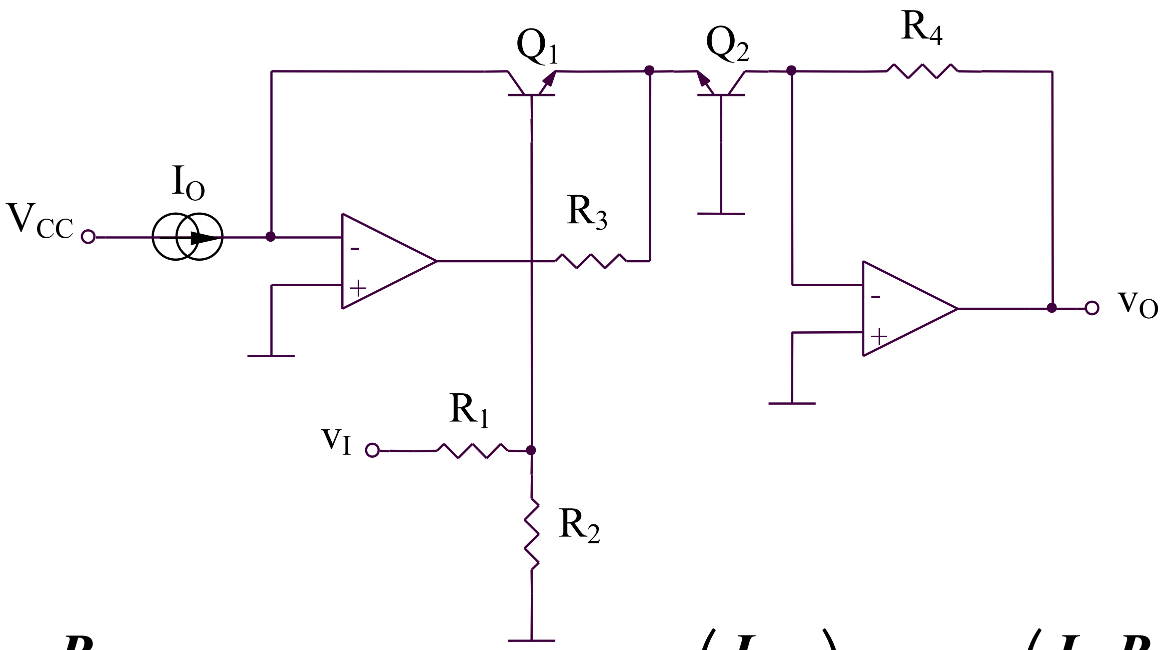
# 2.2.17. Circuit de exponentiere (1)



$$v_I \frac{R_2}{R_1+R_2} = v_{BE1} - v_{BE2} = V_{th} \ln\left(\frac{I_{C1}}{I_{C2}}\right) = V_{th} \ln\left(\frac{I_O R_3}{v_O}\right) \Rightarrow$$

$$\Rightarrow v_O = I_O R_3 e^{-\frac{v_I}{V_{th}} \frac{R_2}{R_1+R_2}}$$

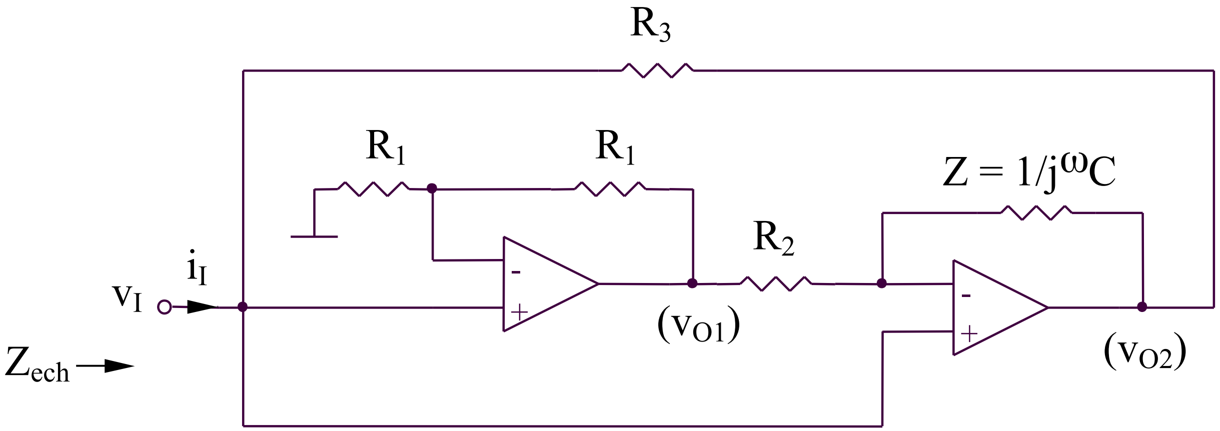
# 2.2.18. Circuit de exponentiere (2)



$$v_I \frac{R_2}{R_1 + R_2} = v_{BE1} - v_{BE2} = V_{th} \ln\left(\frac{I_{C1}}{I_{C2}}\right) = V_{th} \ln\left(\frac{I_O R_4}{v_O}\right) \Rightarrow$$

$$\Rightarrow v_O = I_O R_4 e^{-\frac{v_I}{V_{th}} \frac{R_2}{R_1 + R_2}}$$

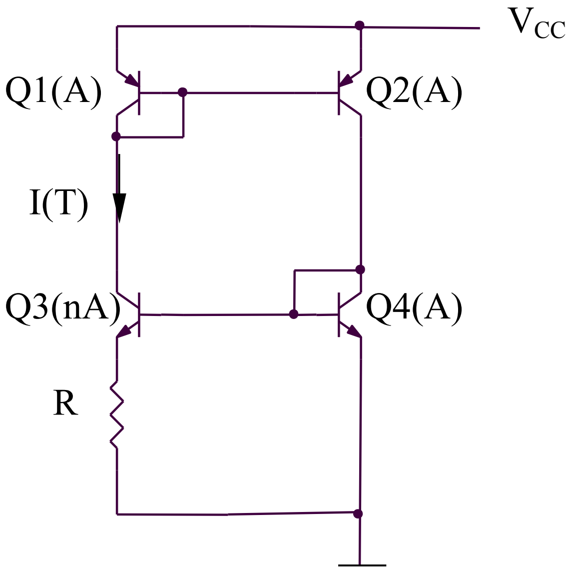
# 2.2.19. Simulator de impedanta



$$\left.\begin{array}{r} v_{O2} = v_I\left(1+\dfrac{Z}{R_2}\right)+v_{O1}\left(-\dfrac{Z}{R_2}\right) \\ v_{O1} = 2v_I \end{array}\right\} \Rightarrow \left.\begin{array}{r} v_{O2} = v_I\left(1-\dfrac{Z}{R_2}\right) \\ i_I = \dfrac{v_I - v_{O2}}{R_3} \end{array}\right\} \Rightarrow i_I = v_I\,\dfrac{Z}{R_2 R_3} \Rightarrow$$

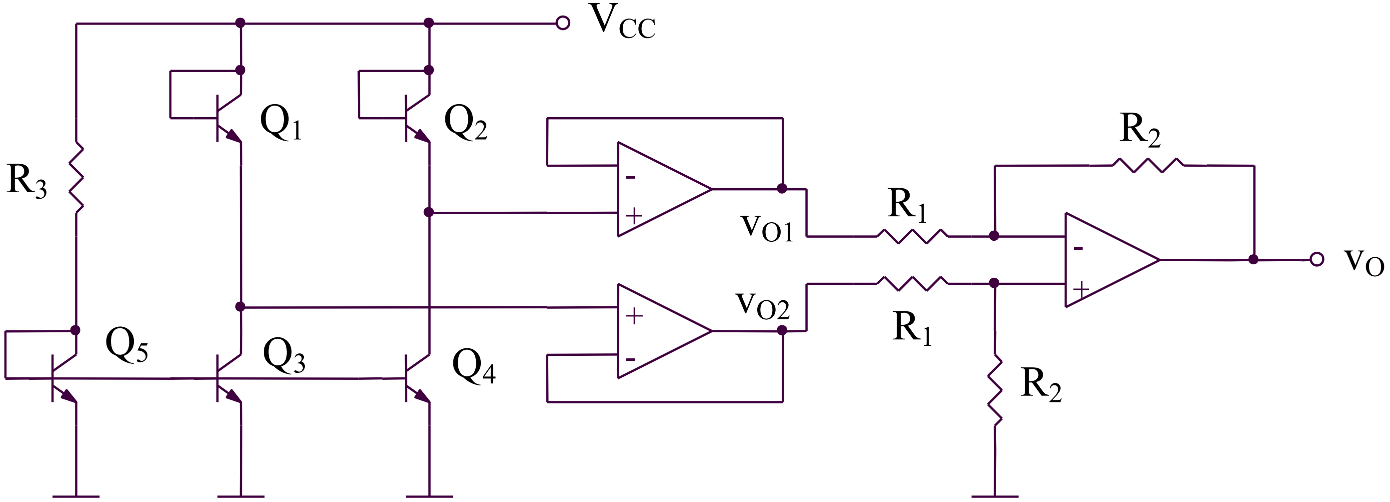
$$\Rightarrow Z_{ech} = \frac{v_I}{i_I} = \frac{R_2R_3}{Z} = j\omega\left(R_2R_3C\right) = j\omega L_{ech} \qquad L_{ech} = R_2R_3C$$

# 2.2.20. Senzori de temperatura (1)



$$I(T) = \frac{V_{BE4} - V_{BE3}}{R} = \frac{V_{th}}{R} ln\left(\frac{I_{C4}}{I_{C3}}\frac{I_{S3}}{I_{S4}}\right) = \frac{V_{th}}{R} ln\, n$$

# 2.2.21. Senzori de temperatura (2)

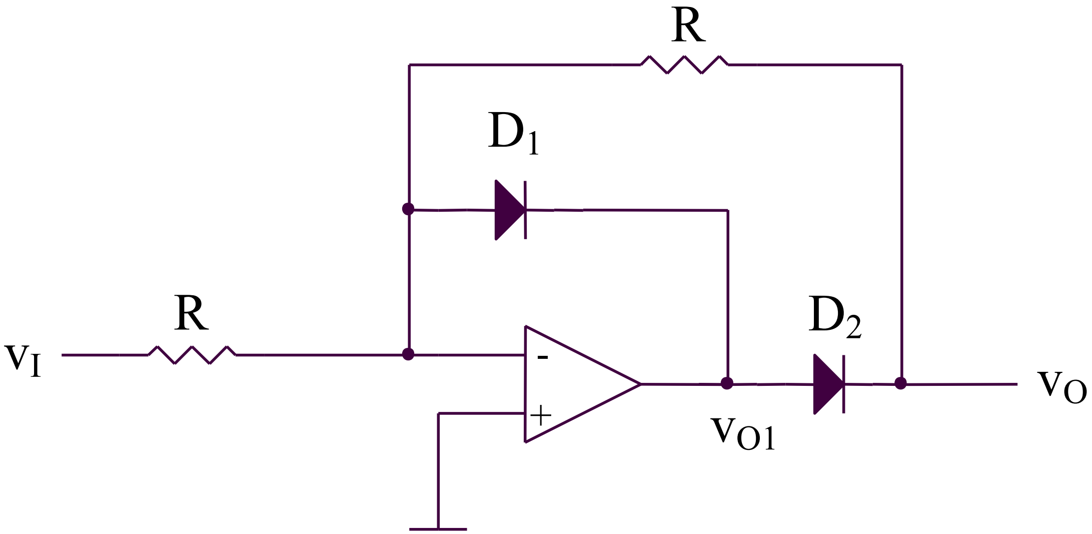


$$v_O = \frac{R_2}{R_1}\left(v_{O2} - v_{O1}\right) = \frac{R_2}{R_1}\left(v_{BE2} - v_{BE1}\right) = \frac{R_2}{R_1} V_{th} \ln\left(\frac{I_{C2}}{I_{C1}}\frac{I_{S1}}{I_{S2}}\right) \Rightarrow$$

$$\Rightarrow v_O = \frac{R_2}{R_1} V_{th} \ln\left(\frac{I_{C4}}{I_{C3}}\frac{I_{S1}}{I_{S2}}\right) = \frac{R_2}{R_1} V_{th} \ln\left(\frac{I_{S4}}{I_{S3}}\frac{I_{S1}}{I_{S2}}\right) = \frac{R_2}{R_1} V_{th} \ln\left(\frac{A_4}{A_3}\frac{A_1}{A_2}\right) = MT$$

$$M = \frac{R_2}{R_1}\frac{k}{q} \ln\left(\frac{A_4}{A_3}\frac{A_1}{A_2}\right)$$

# 2.2.22. Redresor mono-alternanta

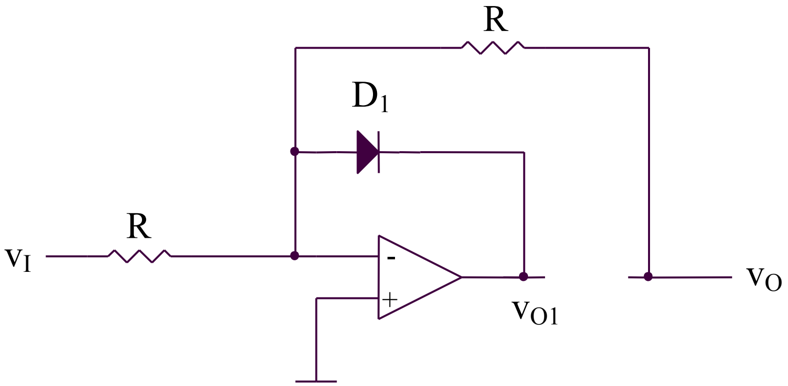


$$v_I > 0 \Rightarrow v_{O1} < 0 \Rightarrow D_1\, deschisa, D_2\, blocata$$

$$v_I < 0 \Rightarrow v_{O1} > 0 \Rightarrow D_2\, deschisa, D_1\, blocata$$

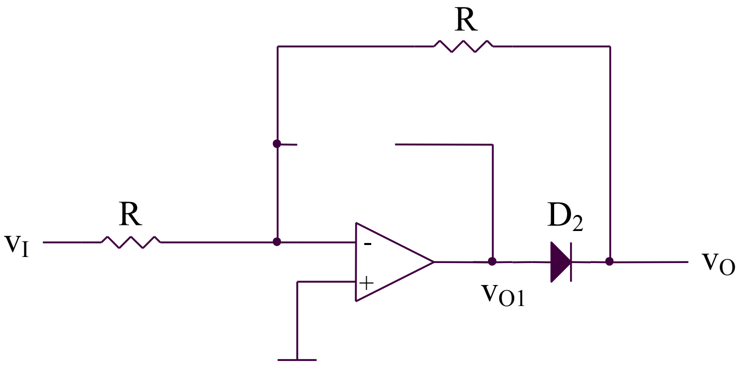
# 2.2.22. Redresor mono-alternanta

$v_I > 0$



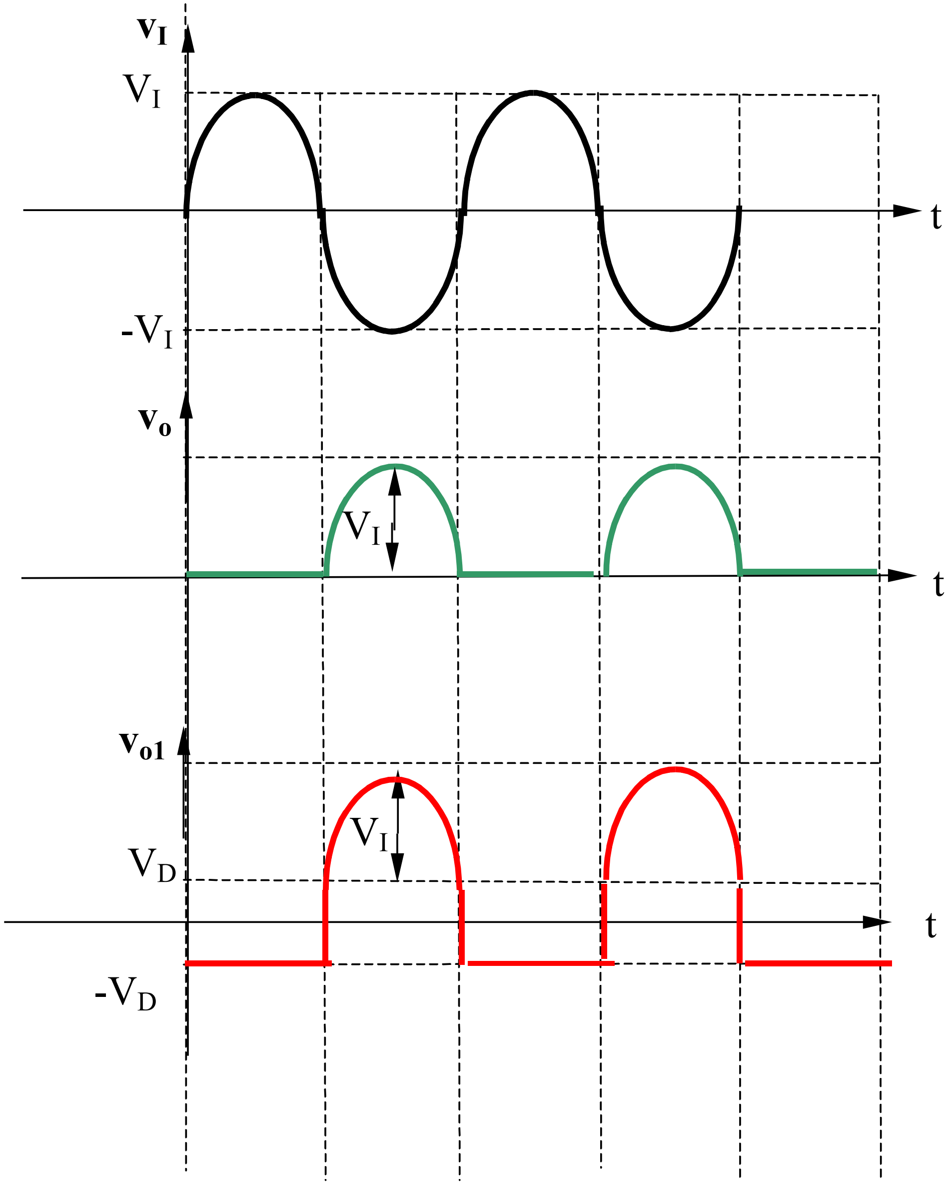
$$v_O = 0$$

$v_I < 0$



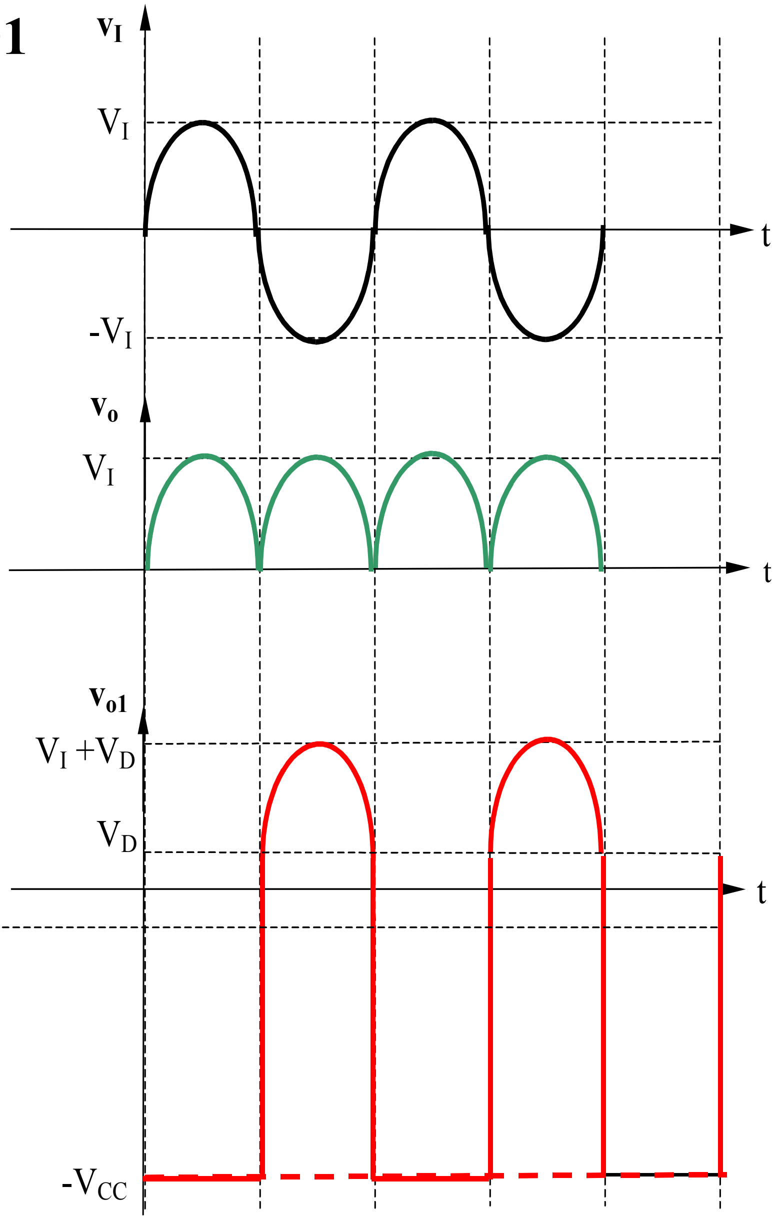
$$v_O = -\frac{R}{R} v_I = -v_I$$

# 2.2.22. Redresor mono-alternanta



# 2.2.22. Redresor mono-alternanta

**Fara D1**



## Exemplu

$f=10kHz$

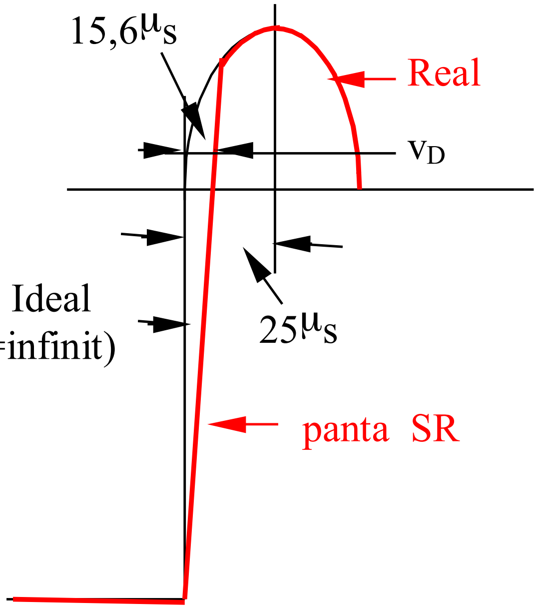
$T=1/f=100\ \mu s$

$T/2=50\ \mu s$

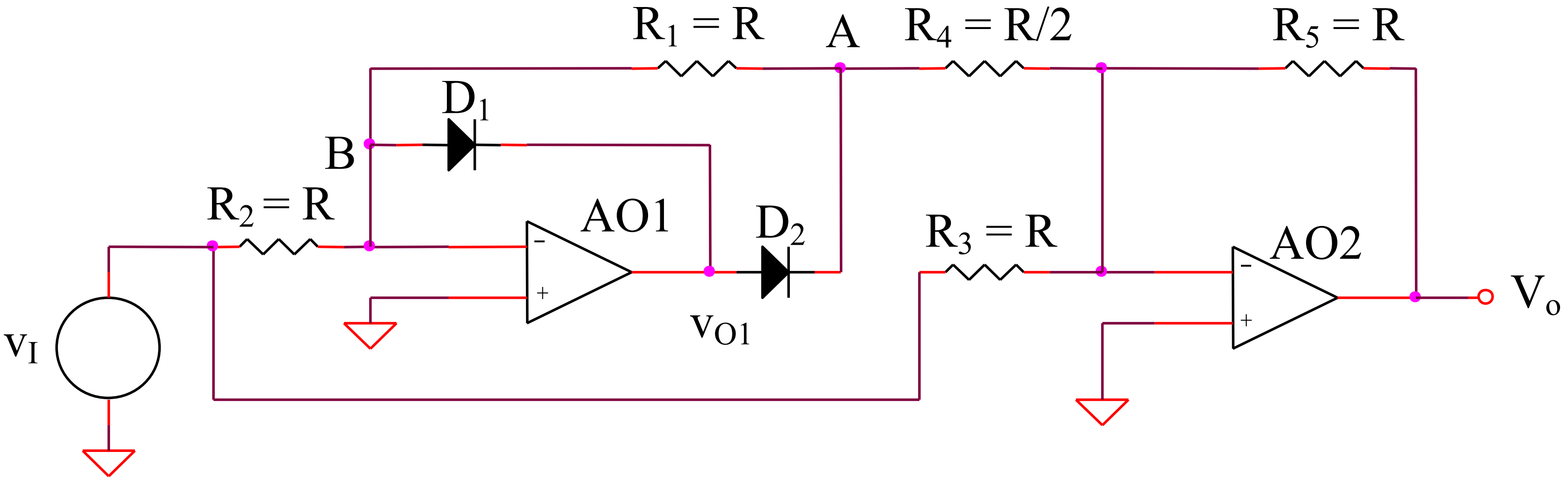
$SR= 1V/\mu s$

$\Delta v_{o1}=(V_{CC} + V_D)=15+0{,}6=15{,}6V$

$\Delta t = \Delta v_{o1}/SR=15{,}6\ \mu s$



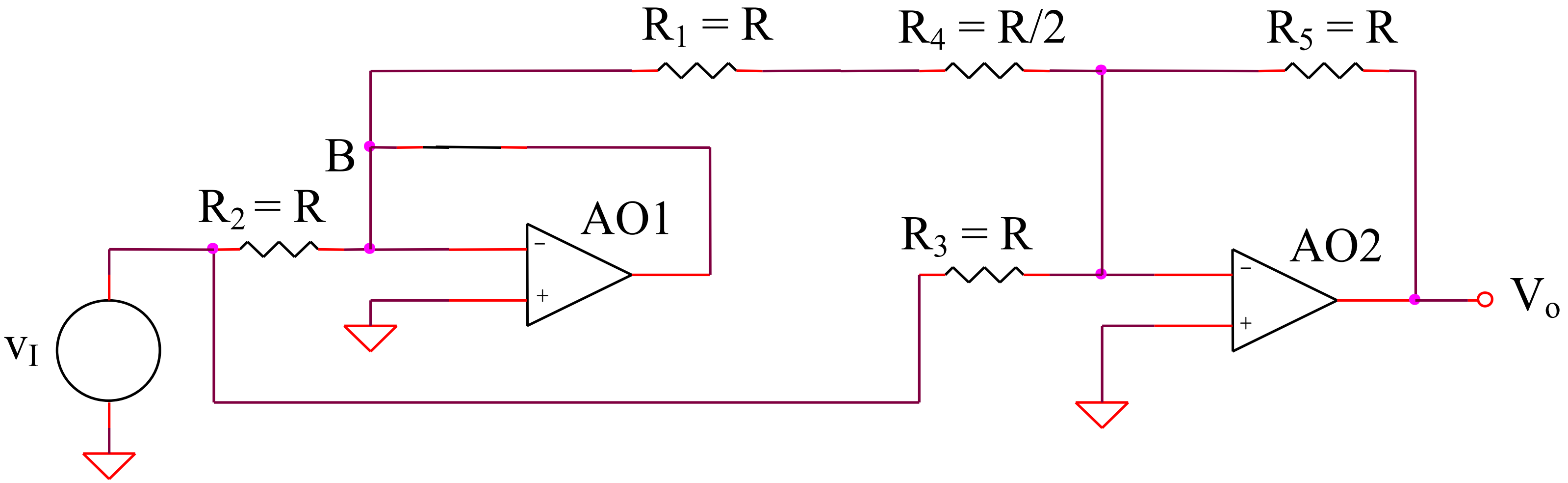
# 2.2.23. Redresor bi-alternanta (1)



$$v_I > 0 \Rightarrow v_{O1} < 0 \Rightarrow D_1 \text{ deschisa}, D_2 \text{ blocata}$$

$$v_I < 0 \Rightarrow v_{O1} > 0 \Rightarrow D_2 \text{ deschisa}, D_1 \text{ blocata}$$

# 2.2.23. Redresor bi-alternanta (1)

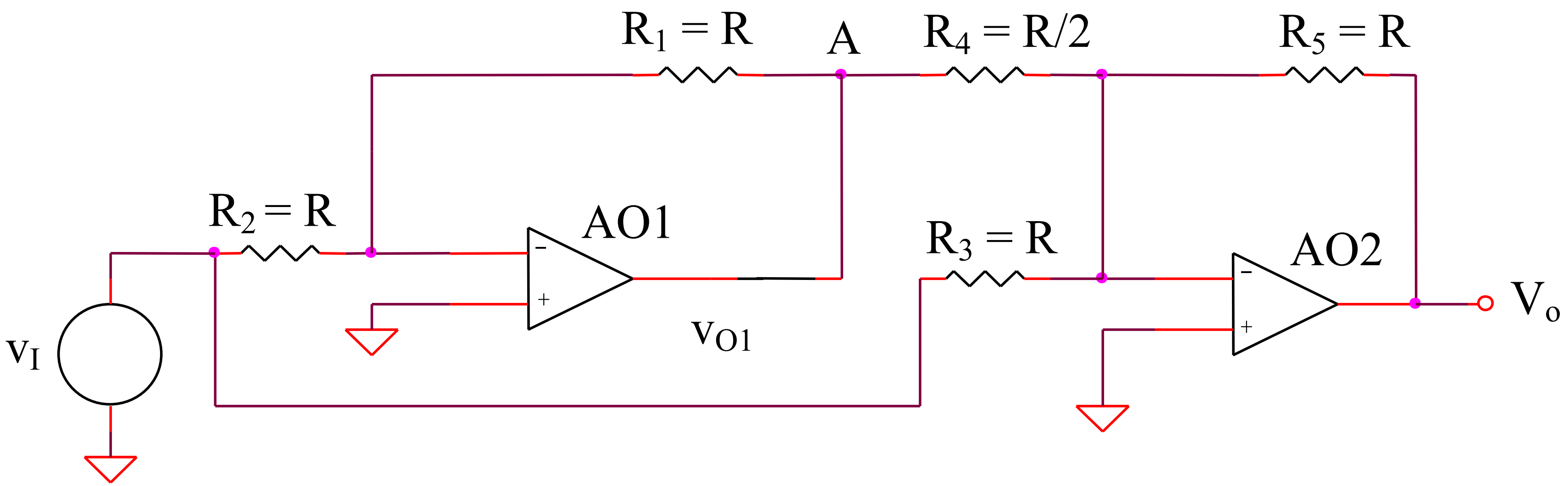


$v_I > 0$

$V_B = 0$

$$v_O = -\frac{R_5}{R_3} v_I = -v_I$$

# 2.2.23. Redresor bi-alternanta (1)



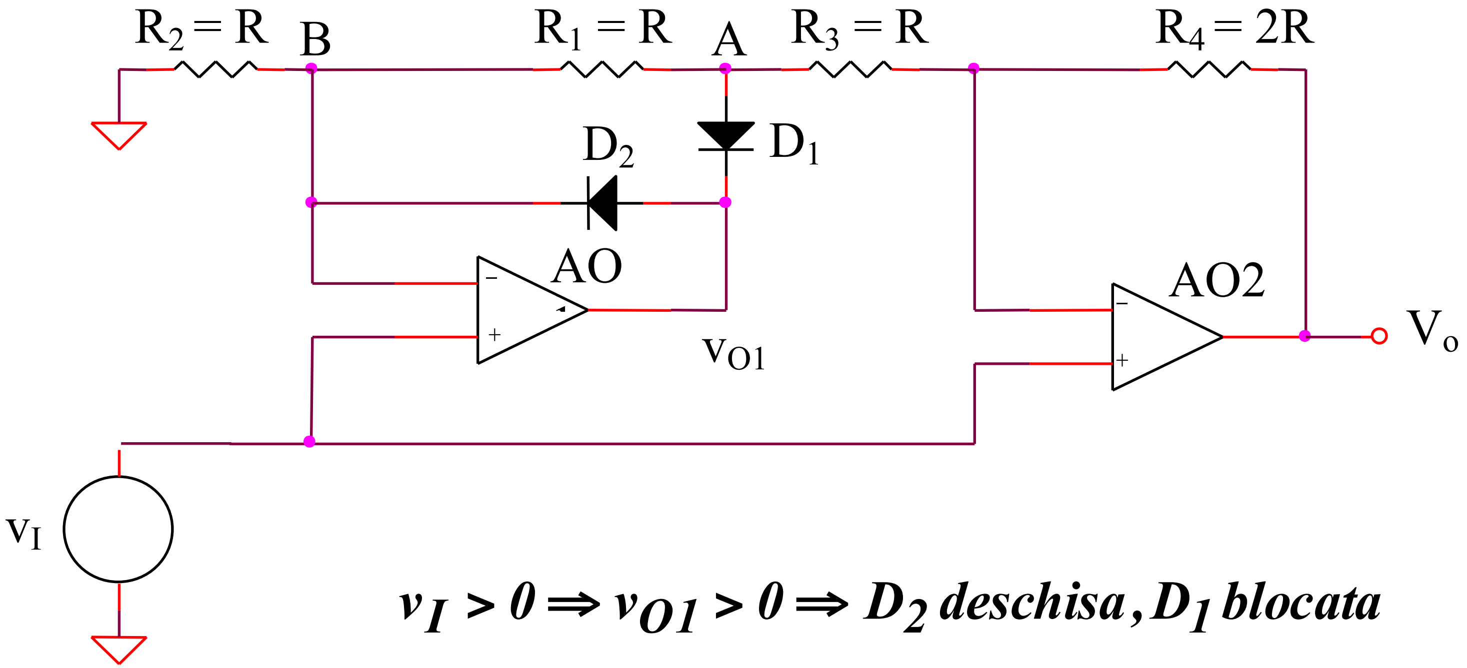
$$v_I < 0$$

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

$$v_O = -\frac{R_5}{R_4} V_A - \frac{R_5}{R_3} v_I = v_I$$

Concluzie: $v_O = -|v_I|$

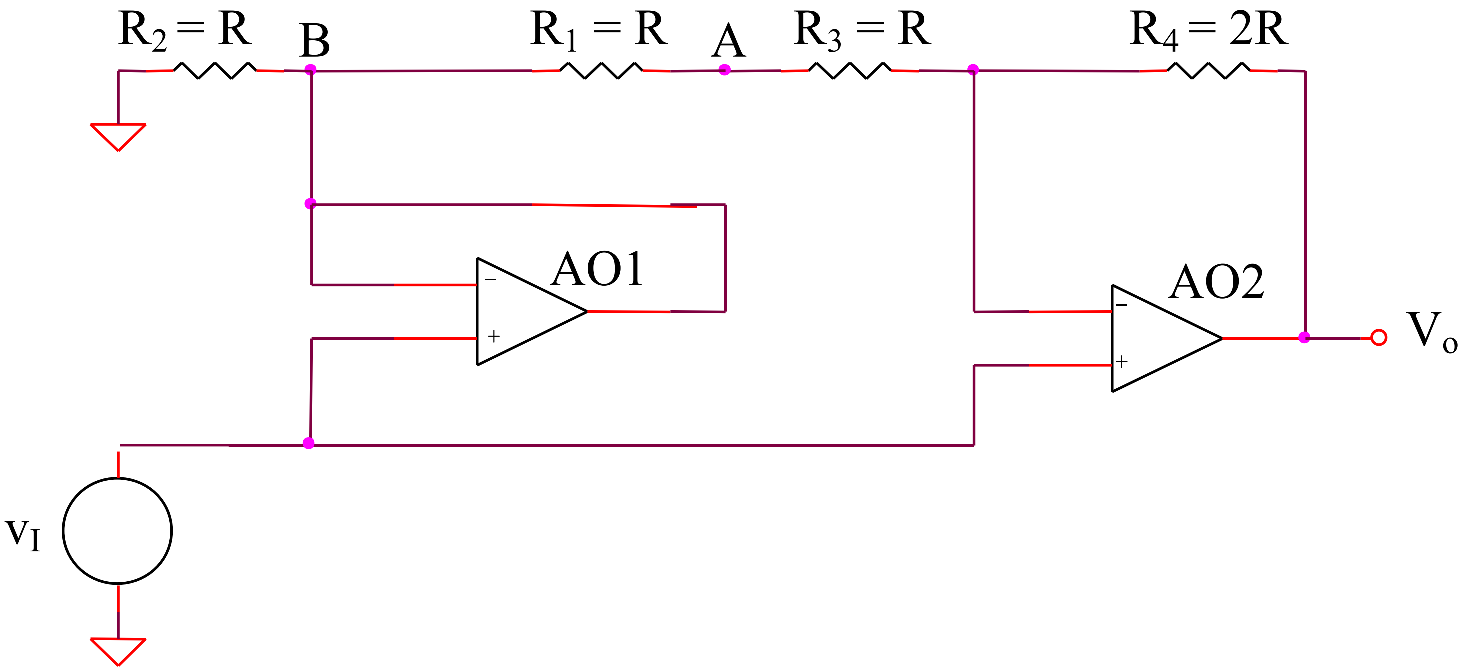
# 2.2.24. Redresor bi-alternanta (2)



$$v_I > 0 \Rightarrow v_{O1} > 0 \Rightarrow D_2\ deschisa, D_1\ blocata$$

$$v_I < 0 \Rightarrow v_{O1} < 0 \Rightarrow D_1\ deschisa, D_2\ blocata$$

# 2.2.24. Redresor bi-alternanta (2)

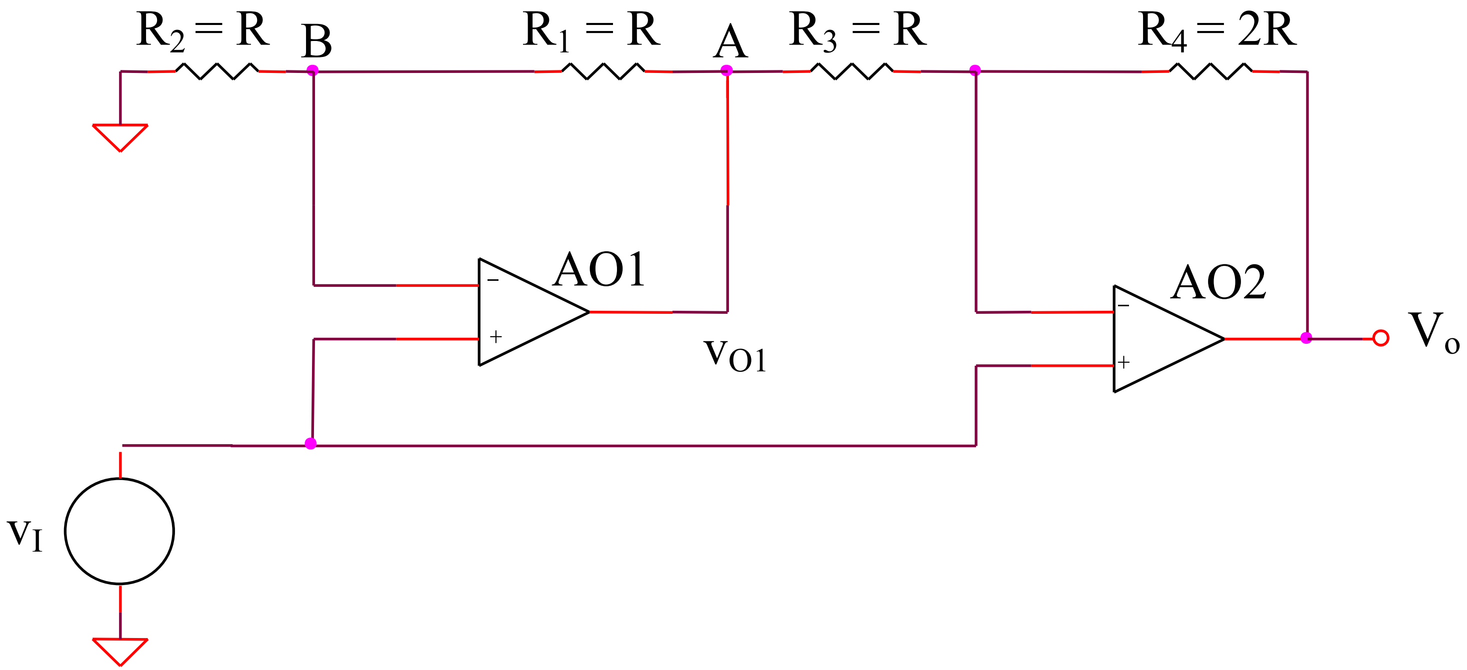


$v_I > 0$

$V_B = v_I$

$$v_O = \left(1 + \frac{R_4}{R_1 + R_3}\right) v_I - \frac{R_4}{R_1 + R_3} V_B = v_I$$

# 2.2.24. Redresor bi-alternanta (2)



$v_I < 0$

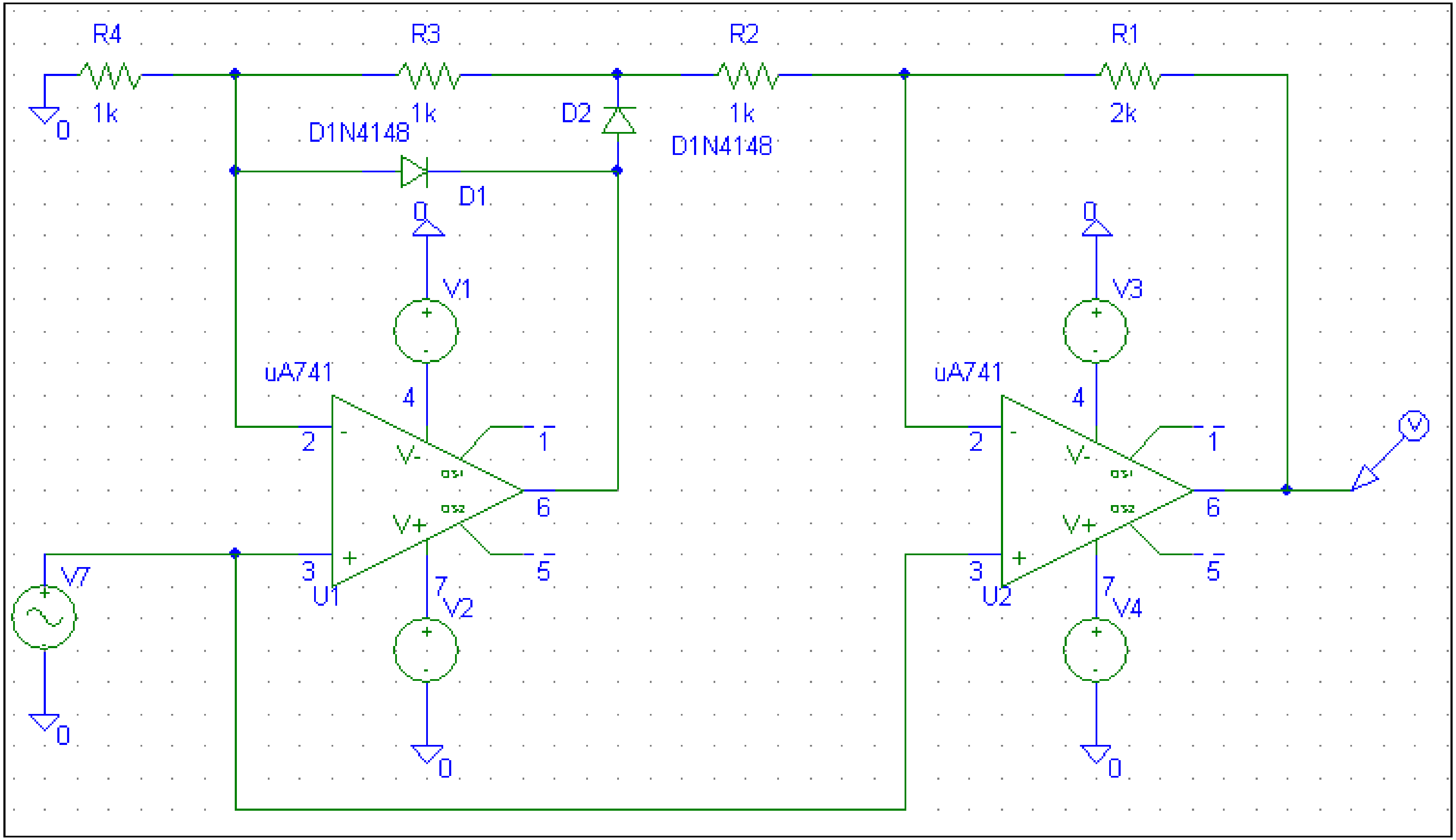
$$V_A = \left(1 + \frac{R_1}{R_2}\right) v_I = 2v_I \qquad v_O = \left(1 + \frac{R_4}{R_3}\right) v_I - \frac{R_4}{R_3} V_A = -v_I$$

Concluzie: $v_O = |v_I|$

# SIMULARI pentru redresorul bialternanta (2)

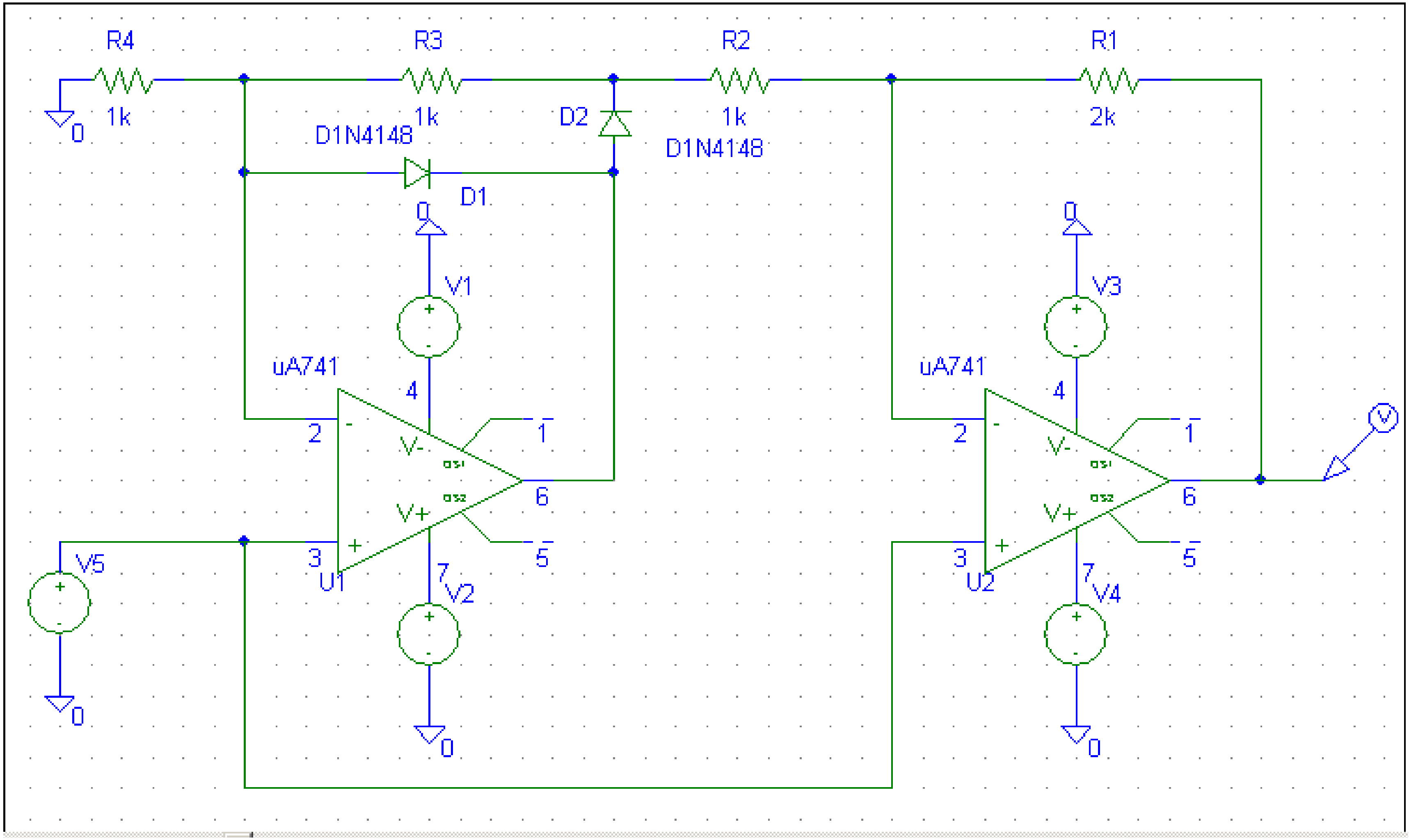
# SIMULARI pentru redresorul bialternanta (2)

## SIM 2.9: $v_O$ (t)

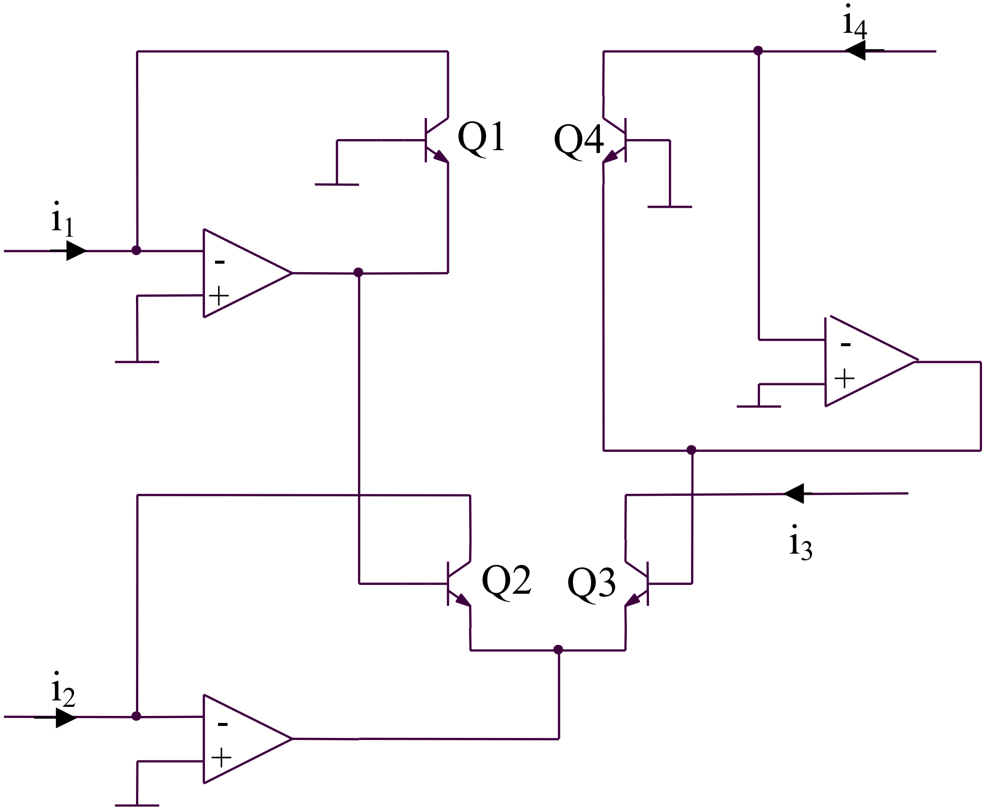


# SIMULARI pentru redresorul bialternanta (2)

## SIM 2.10: $v_O$ ($v_5$)



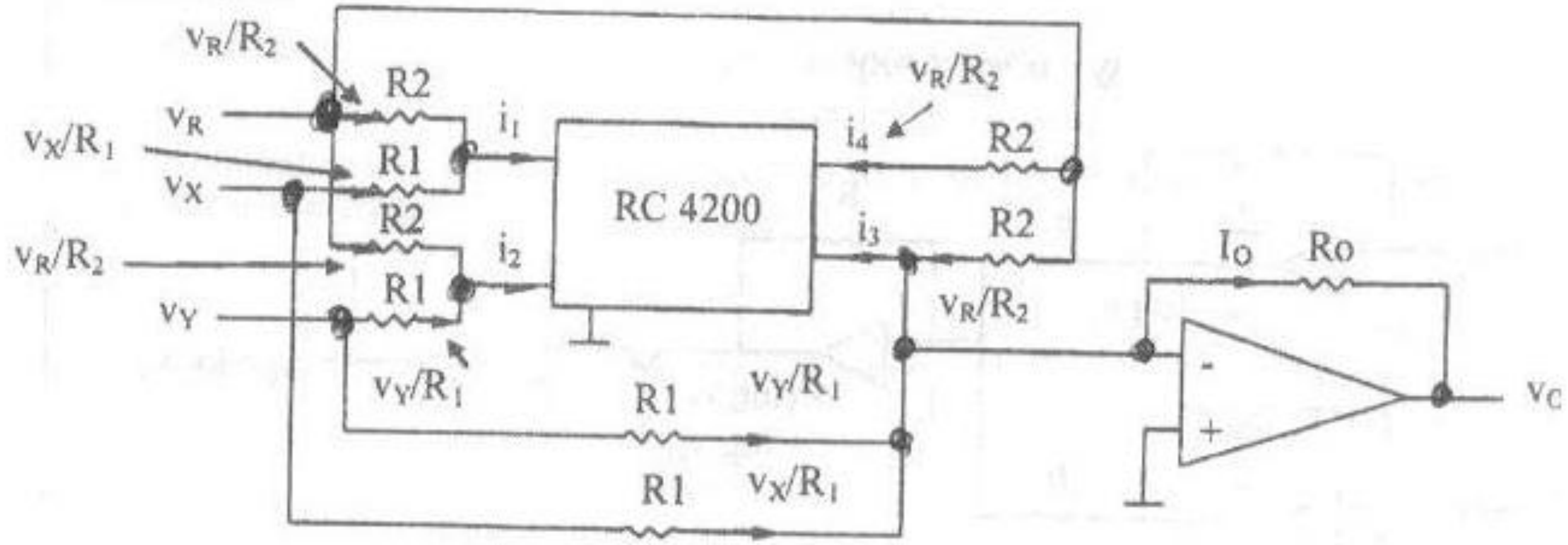
# 2.2.25. Circuit multifunctional RC 4200



$$V_{BE1} + V_{BE2} = V_{BE3} + V_{BE4}$$

$$V_{th} \ln \frac{i_1}{I_S} + V_{th} \ln \frac{i_2}{I_S} = V_{th} \ln \frac{i_3}{I_S} + V_{th} \ln \frac{i_4}{I_S} \Rightarrow i_1 i_2 = i_3 i_4$$

# 2.2.25. Circuit multifunctional RC 4200 - aplicatie

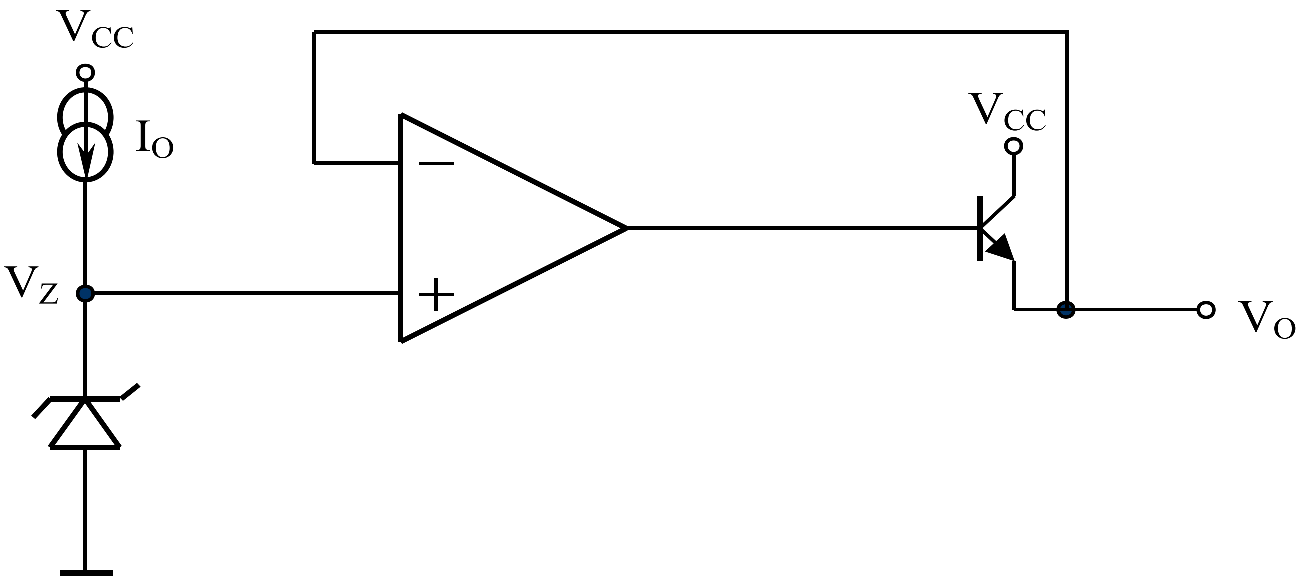


$$i_3 = \frac{i_1 i_2}{i_4} = \frac{R_2}{V_R}\left(\frac{V_R}{R_2}+\frac{V_X}{R_1}\right)\left(\frac{V_R}{R_2}+\frac{V_Y}{R_1}\right) = \frac{V_R}{R_2}+\frac{V_X}{R_1}+\frac{V_Y}{R_1}+\frac{R_2 V_X V_Y}{V_R R_1^2}$$

$$i_O = \frac{V_R}{R_2}+\frac{V_X}{R_1}+\frac{V_Y}{R_1}-\left(\frac{V_R}{R_2}+\frac{V_X}{R_1}+\frac{V_Y}{R_1}+\frac{R_2 V_X V_Y}{V_R R_1^2}\right) = -\frac{R_2 V_X V_Y}{V_R R_1^2}$$

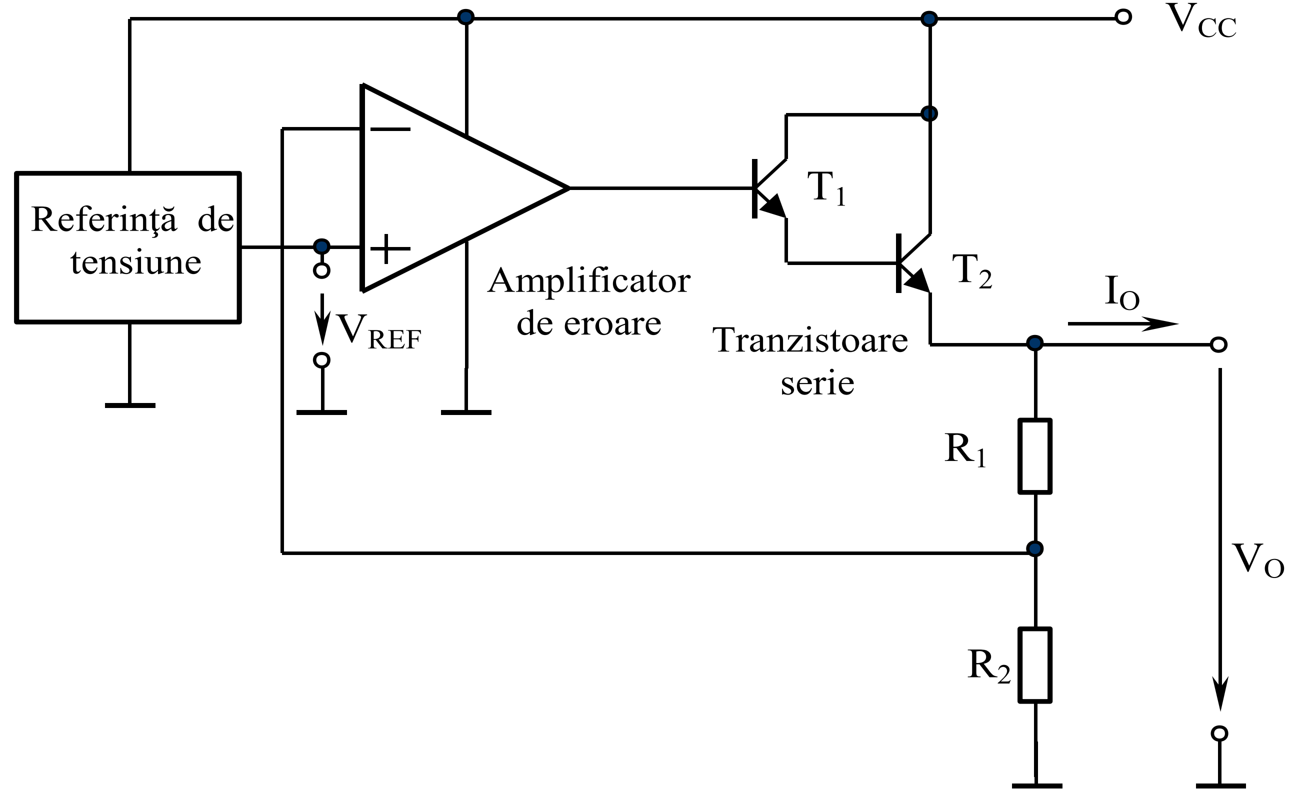
$$v_O = -i_O R_O = \frac{R_2 R_O}{V_R R_1^2} V_X V_Y$$

# 2.2.26. Stabilizator de tensiune (1)



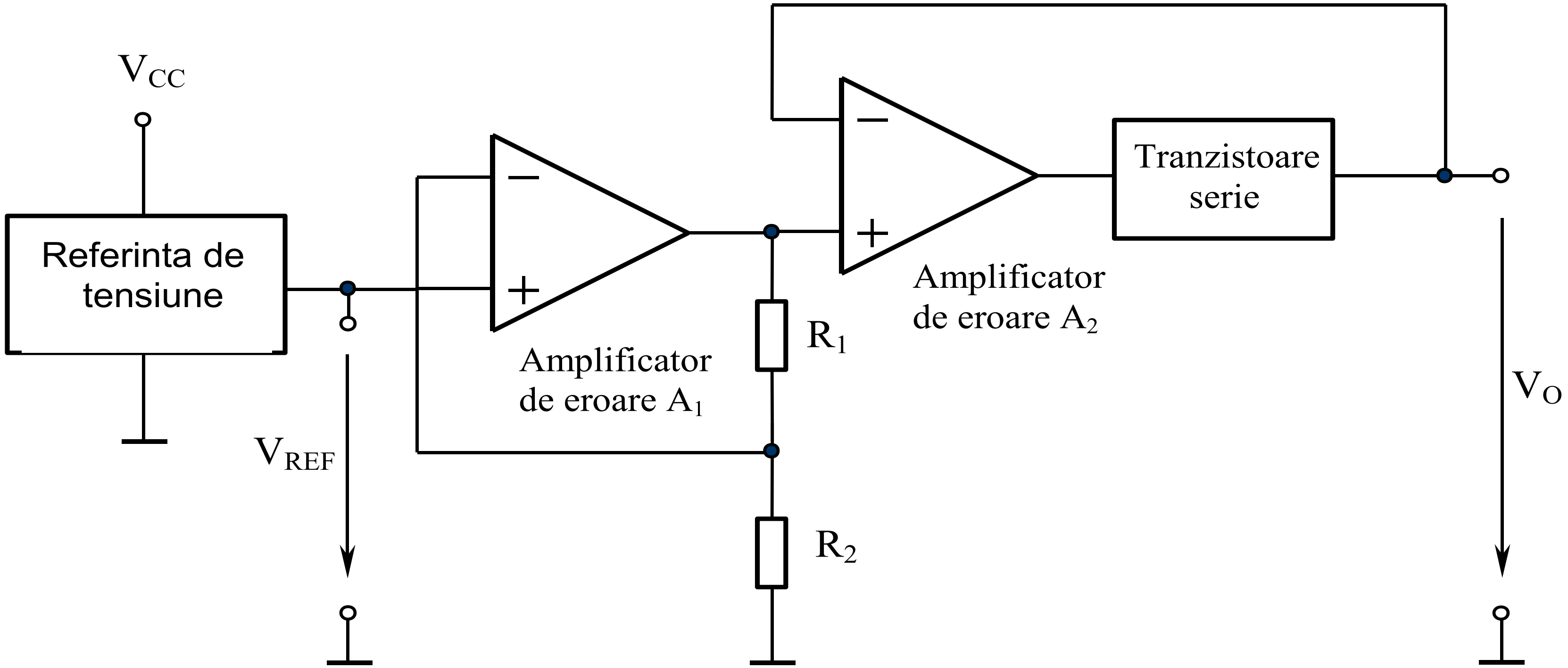
$$V_O = V_Z$$

# 2.2.27. Stabilizator de tensiune (2)



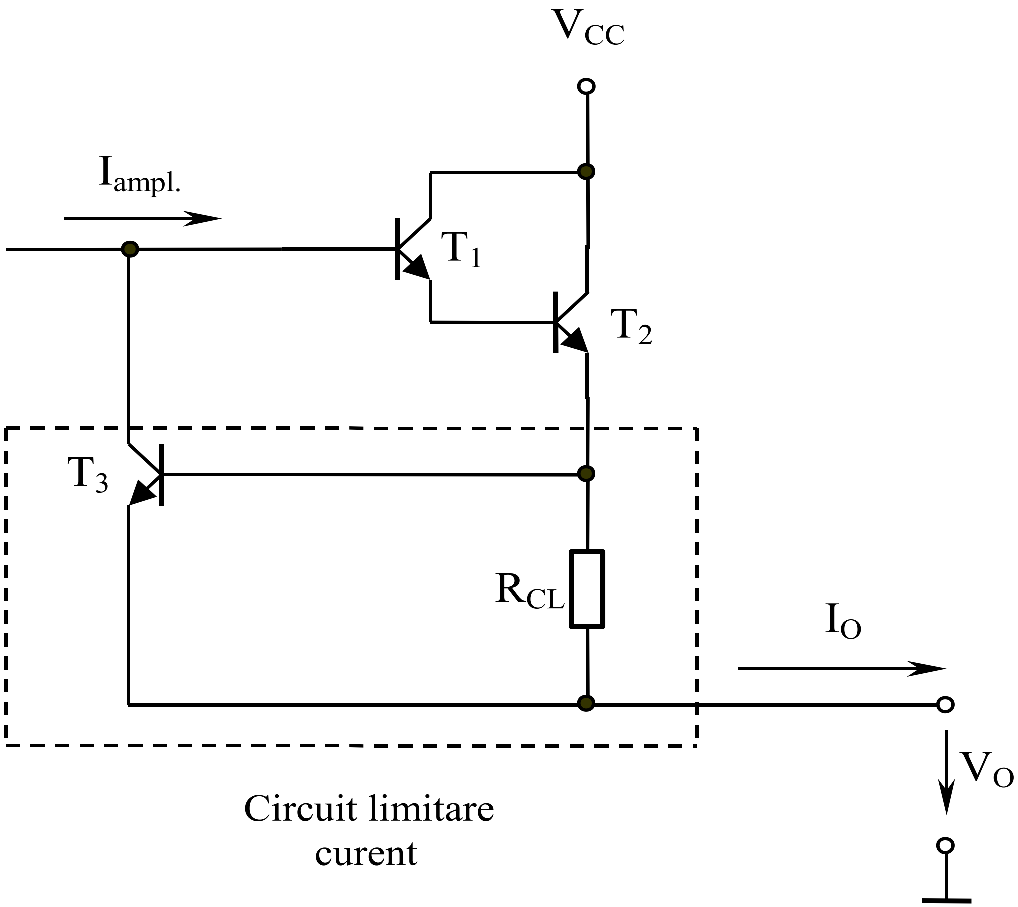
$$V_O \frac{R_2}{R_1 + R_2} = V_{REF} \Rightarrow V_O = V_{REF}\left(1 + \frac{R_1}{R_2}\right)$$

# 2.2.28. Stabilizator de tensiune (3)



$$V_O \frac{R_2}{R_1 + R_2} = V_{REF} \Rightarrow V_O = V_{REF}\left(1 + \frac{R_1}{R_2}\right)$$

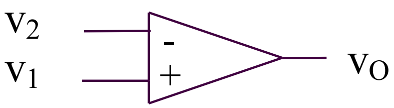
# 2.2.29. Circuit de protectie la supracurent



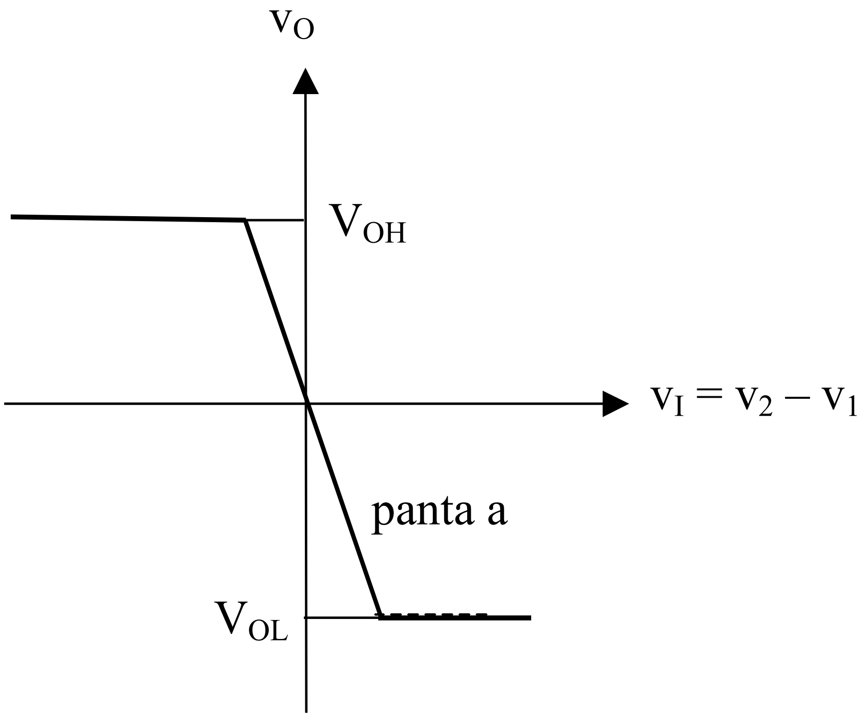
$$I_O = \frac{V_{BE}}{R_{CL}} = \frac{0,65V}{R_{CL}}$$

# 2.3. Comparatoare

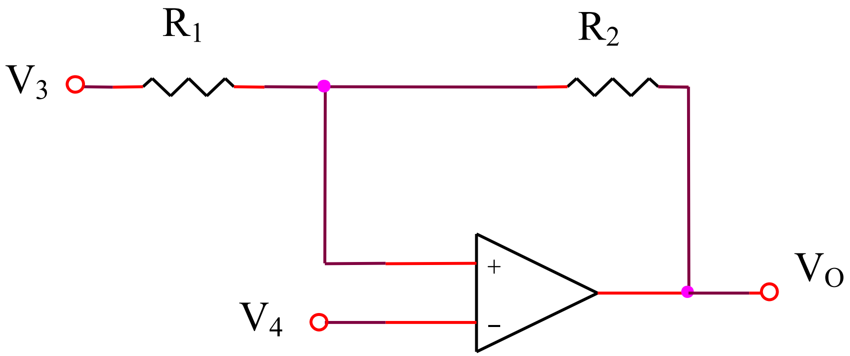
# 2.3.1. Comparator simplu

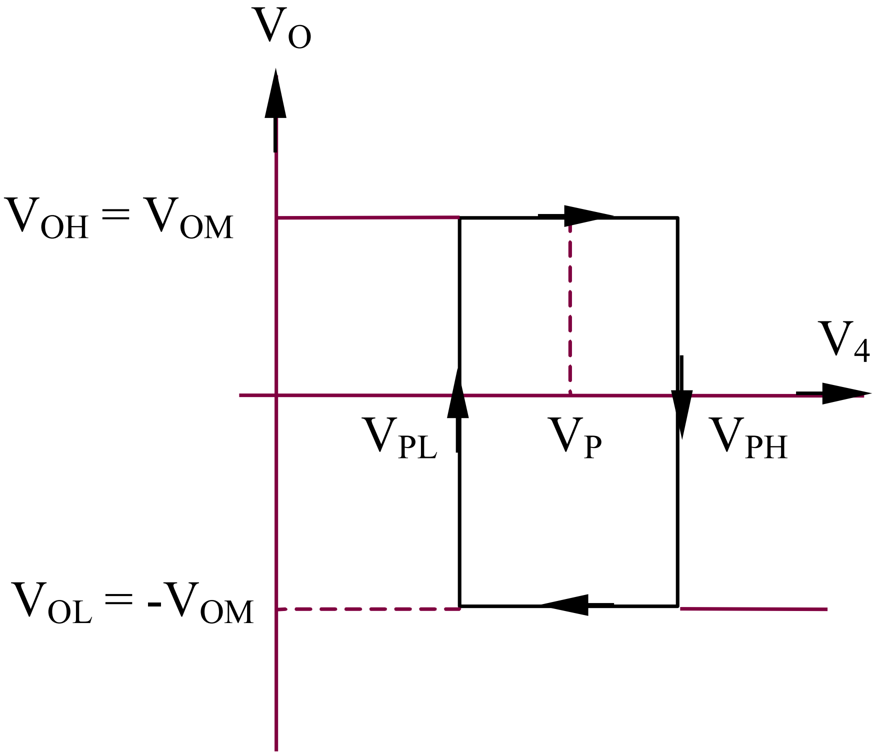


$$v_1 > v_2 \Rightarrow v_O = V_{OH}$$
$$v_1 < v_2 \Rightarrow v_O = V_{OL}$$



# 2.3.2. Comparator cu histerezis





$V_3$ – sursa de tensiune constanta
$V_4$ – sursa de tensiune variabila

$$V_{PL} = V_3 \frac{R_2}{R_1 + R_2} - V_{OH} \frac{R_1}{R_1 + R_2}$$

$$V_{PH} = V_3 \frac{R_2}{R_1 + R_2} + V_{OH} \frac{R_1}{R_1 + R_2}$$

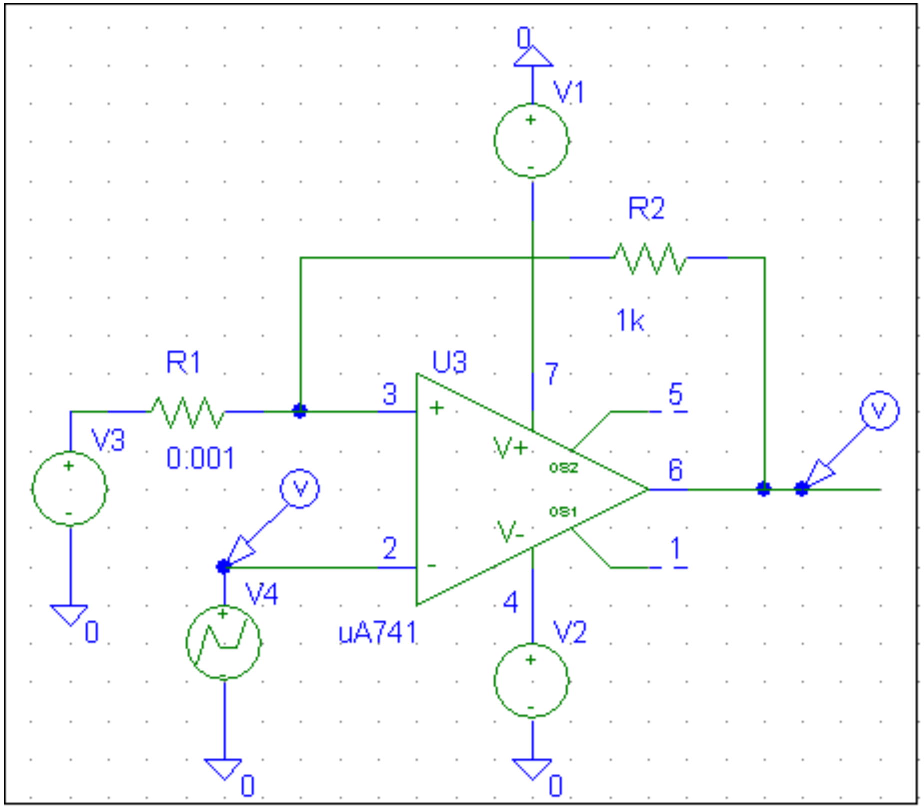
$$\Delta V_P = V_{PH} - V_{PL} = 2V_{OH} \frac{R_1}{R_1 + R_2}$$

$$V_P = \frac{V_{PL} + V_{PH}}{2} = V_3 \frac{R_2}{R_1 + R_2}$$

# SIMULARI pentru comparatorul cu histerezis

# SIMULARI pentru comparatorul cu histerezis

## SIM 2.11: $v_4$ (t), $v_O$ (t)



$V_3 = 2V$

$V_4$ - semnal dreptunghiular

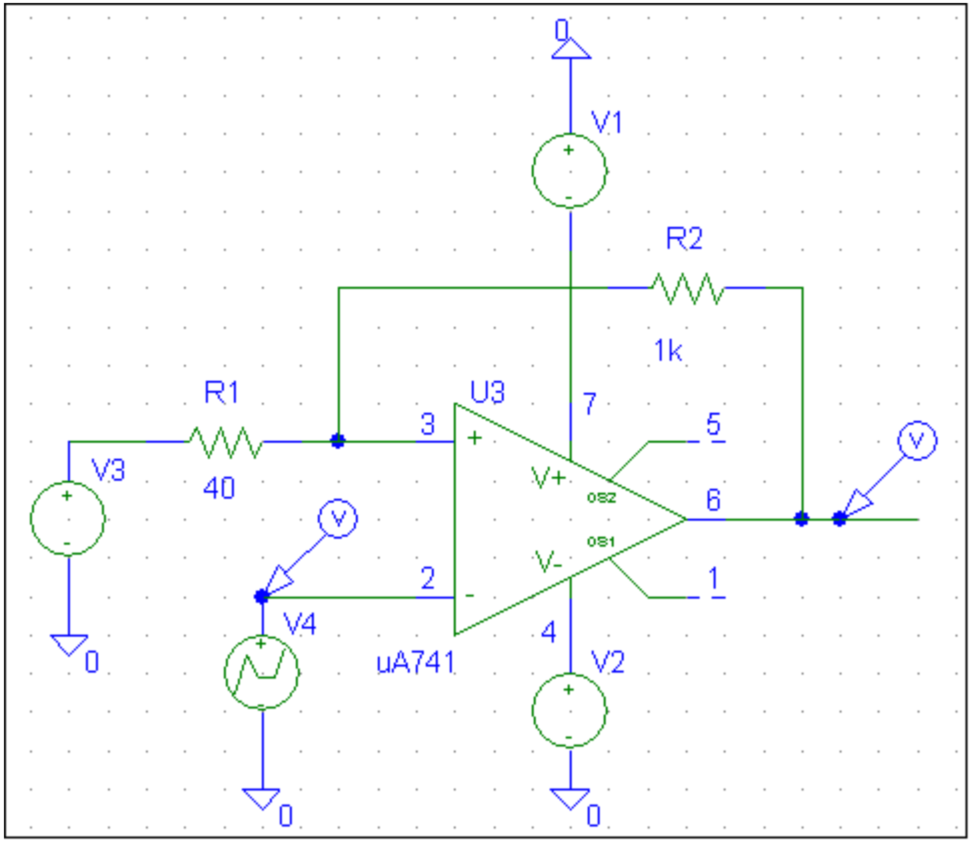
$V_{OM} \cong 8{,}5V$

Latimea ferestrei de histerezis:

$$\Delta V_P = 2V_{OM}\frac{R_1}{R_1 + R_2} \cong 0$$

# SIMULARI pentru comparatorul cu histerezis

## SIM 2.12: $v_4$ (t), $v_O$ (t)



$V_3 = 2V$

$V_4$ - semnal dreptunghiular

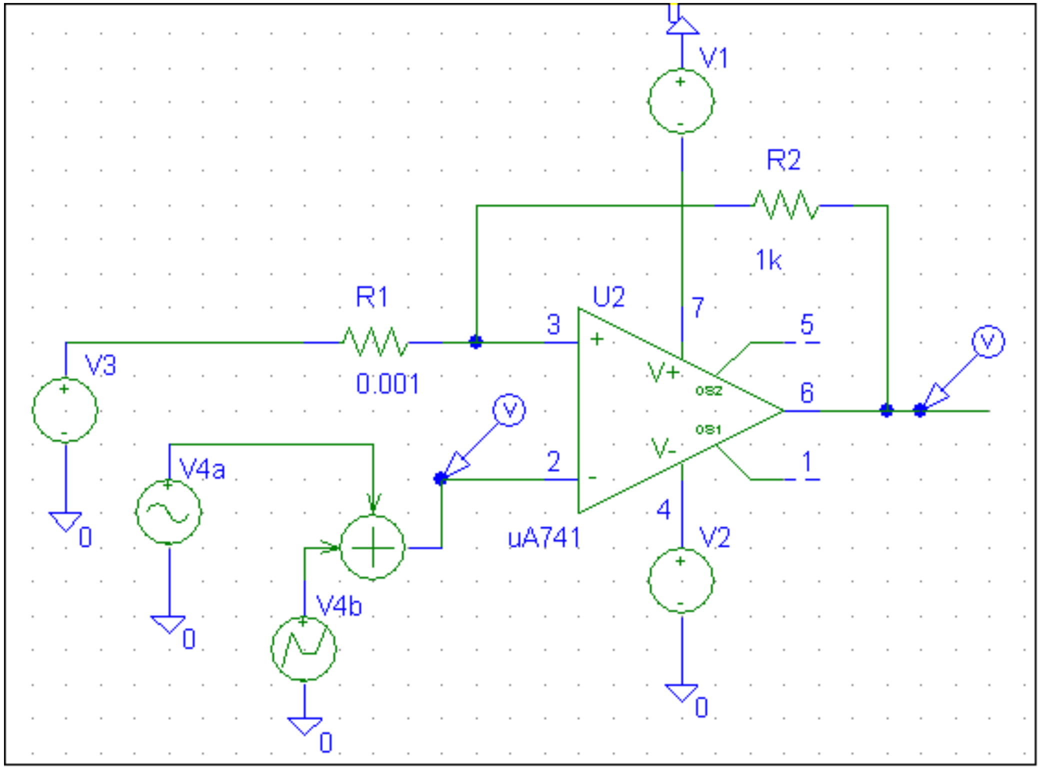
$V_{OM} \cong 8{,}5V$

Latimea ferestrei de histerezis:

$$\Delta V_P = 2V_{OM}\frac{R_1}{R_1 + R_2} \cong 650mV$$

# SIMULARI pentru comparatorul cu histerezis

## **SIM 2.13:** $v_4$ (t), $v_O$ (t)



$V_3 = 2V$

$V_4$ - zgomot de amplitudine maxima 400mV, suprapus peste un semnal dreptunghiular

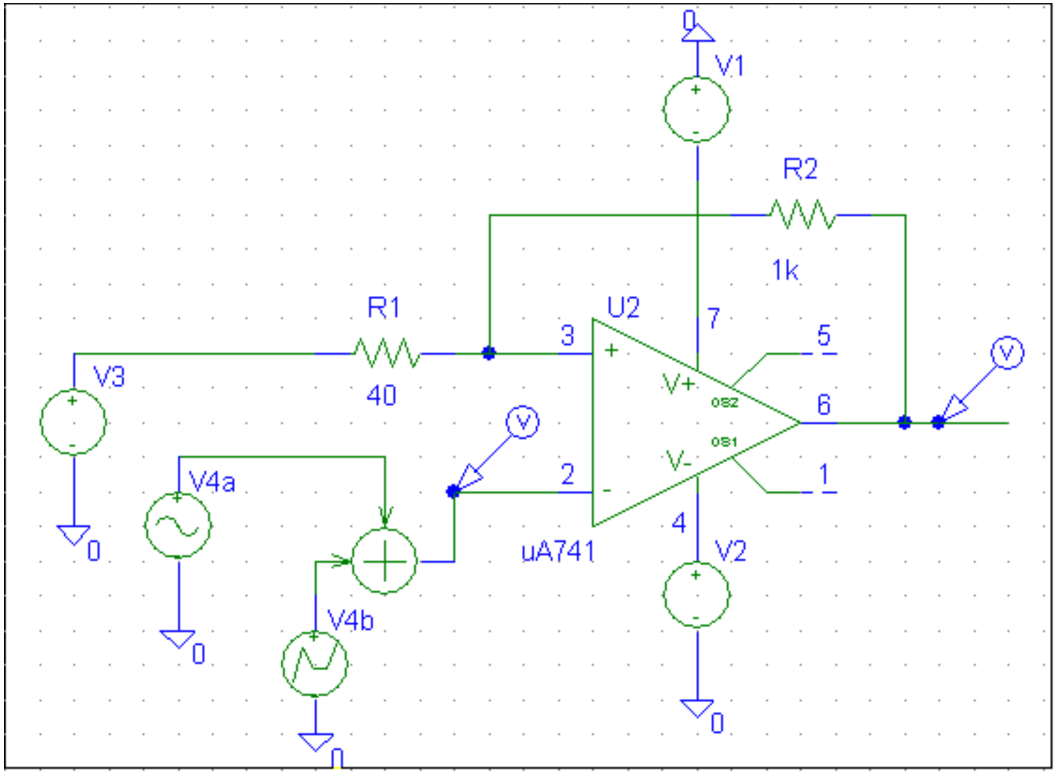
$V_{OM} \cong 8{,}5V$

Latimea ferestrei de histerezis (mai mica decat amplitudinea maxima a zgomotului):

$$\Delta V_P = 2V_{OM}\frac{R_1}{R_1 + R_2} \cong 0$$

# SIMULARI pentru comparatorul cu histerezis

## SIM 2.14: $v_4$ (t), $v_O$ (t)



$V_3 = 2V$

$V_4$ - zgomot de amplitudine maxima 400mV, suprapus peste un semnal dreptunghiular

$V_{OM} \cong 8{,}5V$

Latimea ferestrei de histerezis (mai mare decat amplitudinea maxima a zgomotului):

$$\Delta V_P = 2V_{OM}\frac{R_1}{R_1 + R_2} \cong 650mV$$

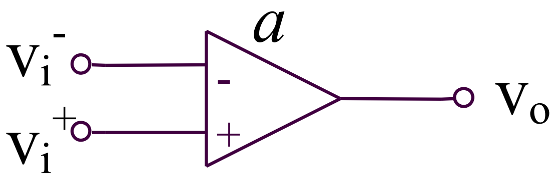
# 2.4. Deviatii de la idealitate si limitari ale AO real

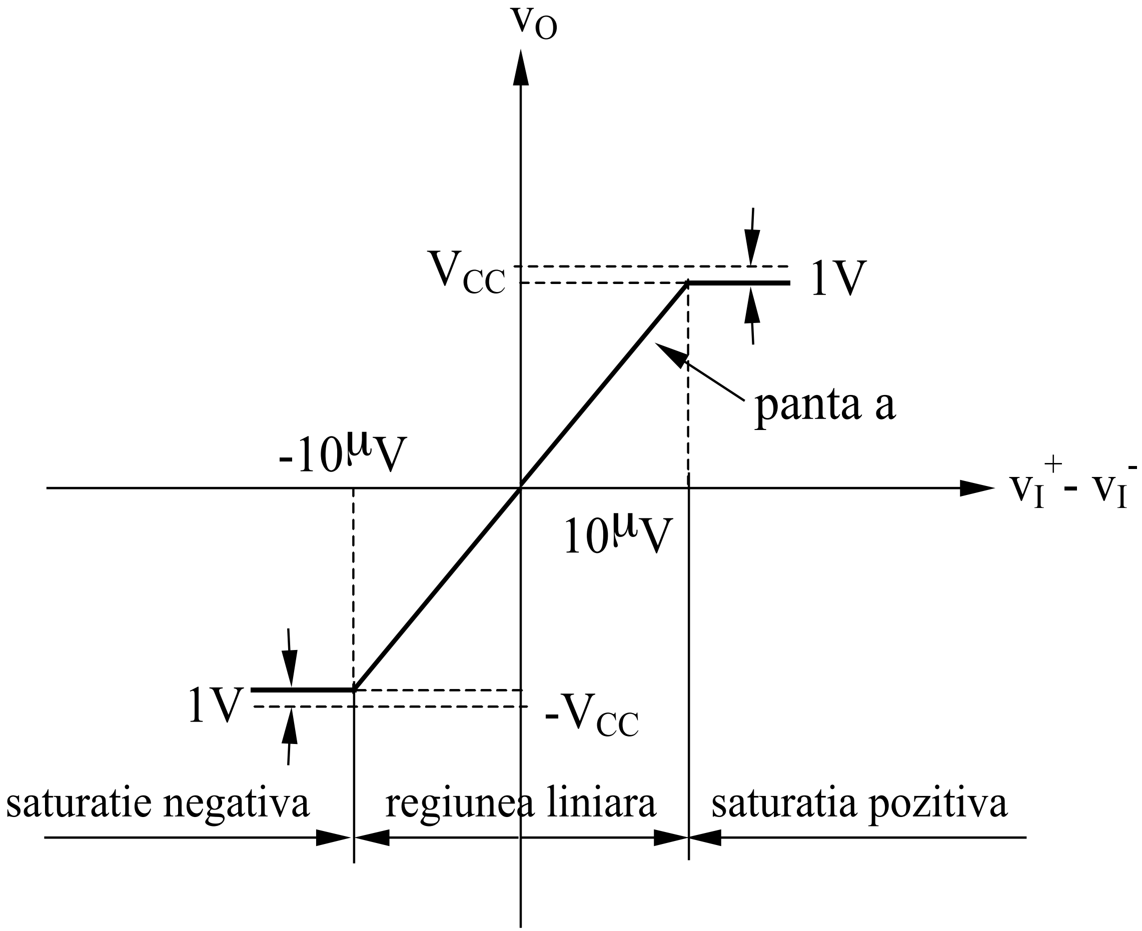
| **Parametri (AO bipolar)** | **Ordin de marime** |
|---|---|
| • amplificare in tensiune | $a > 10^5$ |
| • tensiune de intrare de offset | $v_{IO} = 2mV$ |
| • curenti de polarizare a intrarilor | $I_B = 80\ nA$ |
| • curent de intrare de offset | $I_{IO} = 5nA$ |
| • impedanta de intrare | $R_i = 2M\Omega$ |
| • domeniul tensiunii de intrare de mod comun | $[v_{ICmin,}\ v_{ICmax}]$ |
| • excursia maxima a tensiunii de iesire | $[v_{Omin,}\ v_{Omax}]$ |
| • curentul maxim de iesire | $I_{Omax}$ (zeci mA) |
| • factor de rejectie a tensiunii de mod comun | CMRR = 80dB |
| • factor de rejectie a tensiunii de alimentare | PSRR = 80-120dB |
| • impedanta de iesire | $R_O = 75\Omega$ |
| • frecventa de amplificare unitara | $f_U = 1MHz$ |
| • slew-rate | $SR = (0{,}2\text{-}1)V/\mu s$ |

# 2.4. Deviatii de la idealitate si limitari ale AO real

## 2.4.1. Valoarea finita a amplificarii in bucla deschisa (*a*)

### *Exemplu 1: Utilizarea unui AO real pentru realizarea unui comparator de tensiune*





In regiunea liniara:

$$v_O = a\left(v_I^+ - v_I^-\right)$$

In saturatia negativa:

$$v_O \cong -\left(V_{CC} - 1V\right)$$

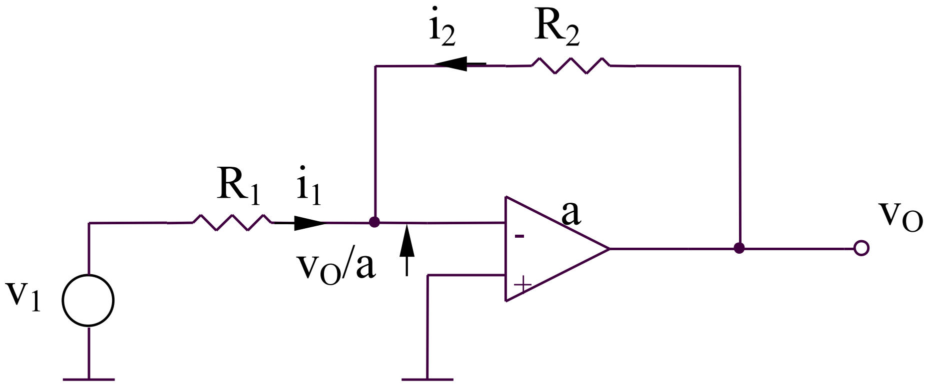
In saturatia pozitiva:

$$v_O \cong V_{CC} - 1V$$

# 2.4. Deviatii de la idealitate si limitari ale AO real

## 2.4.1. Valoarea finita a amplificarii in bucla deschisa (*a*)

### *Exemplu 2: Amplificatorul inversor*



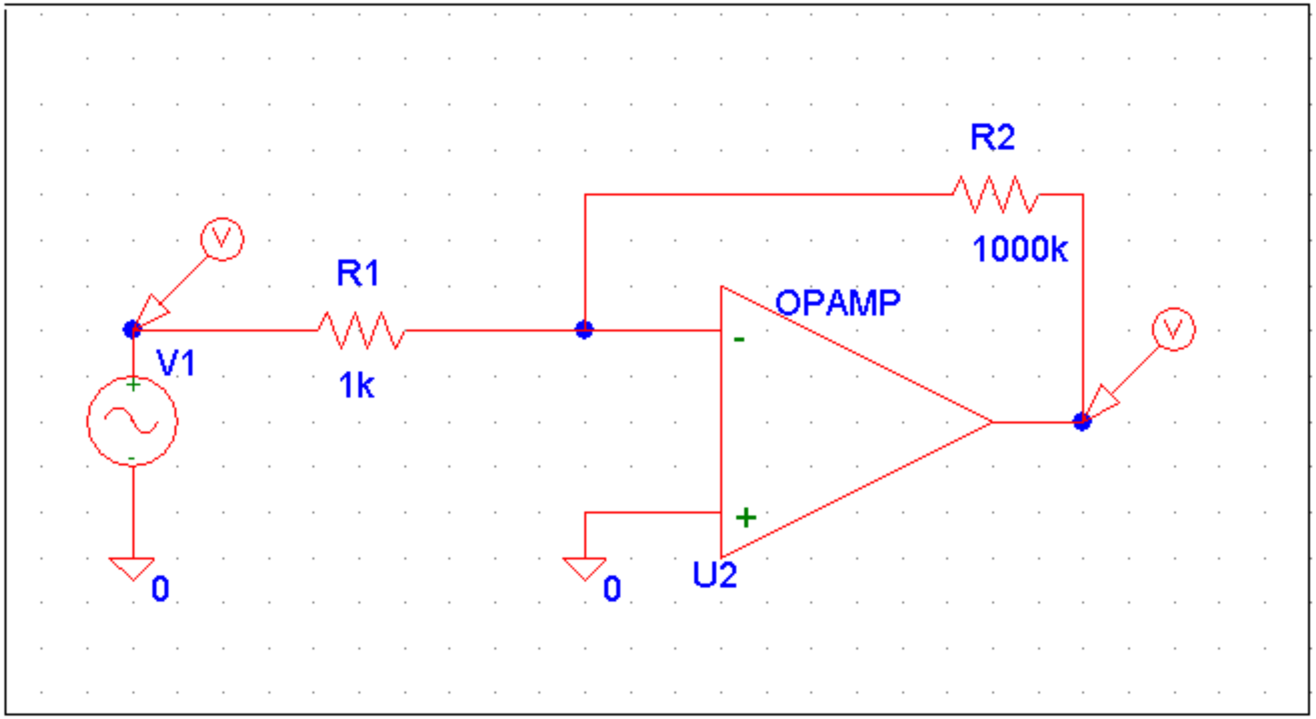
$$\frac{v_1 + \frac{v_O}{a}}{R_1} + \frac{v_O + \frac{v_O}{a}}{R_2} = 0 \Rightarrow$$

$$\Rightarrow A_{real} = \frac{v_O}{v_1} = -\frac{R_2}{R_1}\frac{1}{1 + \frac{1}{a}\frac{R_1 + R_2}{R_1}} \xrightarrow{a\to\infty} A_{ideal} = -\frac{R_2}{R_1}$$

# SIMULARI pentru evaluarea erorilor introduse de valoarea redusa a amplificarii in bucla deschisa (a)

# SIMULARI pentru evaluarea erorilor introduse de valoarea redusa a amplificarii in bucla deschisa (a)

## SIM 2.15: $v_1$ (t), $v_O$ (t)



$$v_1(t) = V_{AMPL} \sin(2\pi f t)$$

$$V_{AMPL} = 0{,}1mV$$

$$f = 1kHz$$

$$a = 10^3$$

# SIMULARI pentru evaluarea erorilor introduse de valoarea redusa a amplificarii in bucla deschisa (a)

## SIM 2.15: $v_1$ (t), $v_O$ (t) (continuare)

$$A_{real} = -\frac{R_2}{R_1}\frac{1}{1+\frac{1}{a}\left(1+\frac{R_2}{R_1}\right)}$$

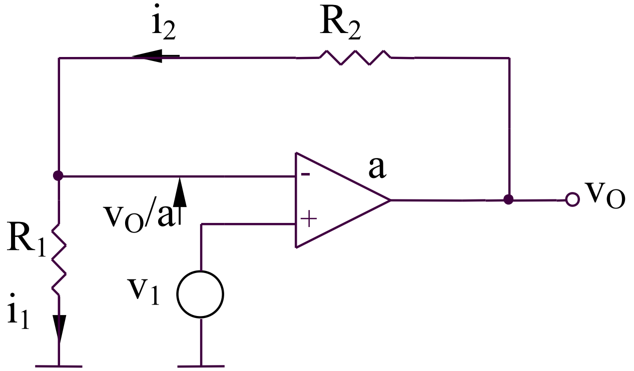
$$A_{real} = -10^3\frac{1}{1+\frac{1}{10^3}\left(1+10^3\right)}$$

$$A_{real} = -\frac{10^3}{2} = \frac{A_{ideal}}{2}$$

# 2.4. Deviatii de la idealitate si limitari ale AO real

## 2.4.1. Valoarea finita a amplificarii in bucla deschisa (a)

### *Exemplu 3: Amplificatorul neinversor*



$$\frac{v_1 - \dfrac{v_O}{a}}{R_1} = \frac{v_O - \left(v_1 - \dfrac{v_O}{a}\right)}{R_2}$$

$$A = \frac{v_O}{v_1} = \frac{R_1 + R_2}{R_1}\frac{1}{1 + \dfrac{R_1 + R_2}{aR_1}} \xrightarrow{a \to \infty} 1 + \frac{R_2}{R_1}$$

# 2.4. Deviatii de la idealitate si limitari ale AO real

## 2.4.2. Curentul de polarizare a intrarilor ($I_B$)

Reprezinta media aritmetica a curentilor de intrare in AO.

$$I_B = \frac{I_{B1} + I_{B2}}{2}$$

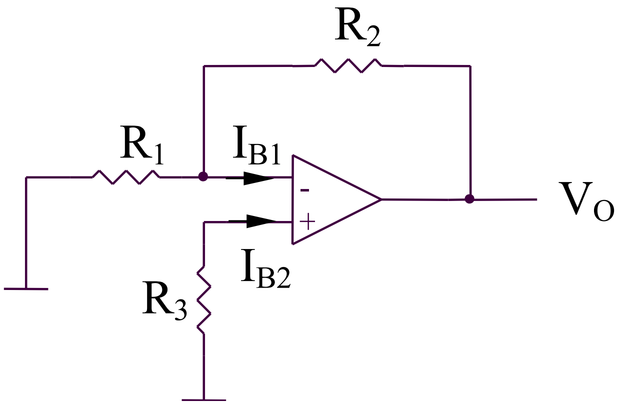
Valori tipice:

- 10-100 nA – pentru etaje de intrare realizate in tehnologia bipolara
- < 0,001pA – pentru etaje de intrare realizate in tehnologia MOS

# 2.4. Deviatii de la idealitate si limitari ale AO real

## 2.4.2. Curentul de polarizare a intrarilor ($I_B$)

### *Metoda de compensare a erorilor introduse de curentul $I_B$*



$$V_O = -I_{B2} R_3 \left( 1 + \frac{R_2}{R_1} \right) + I_{B1} R_2$$

Daca: $I_{B1} = I_{B2}$ si $R_3 = R_1 // R_2 = \dfrac{R_1 R_2}{R_1 + R_2}$

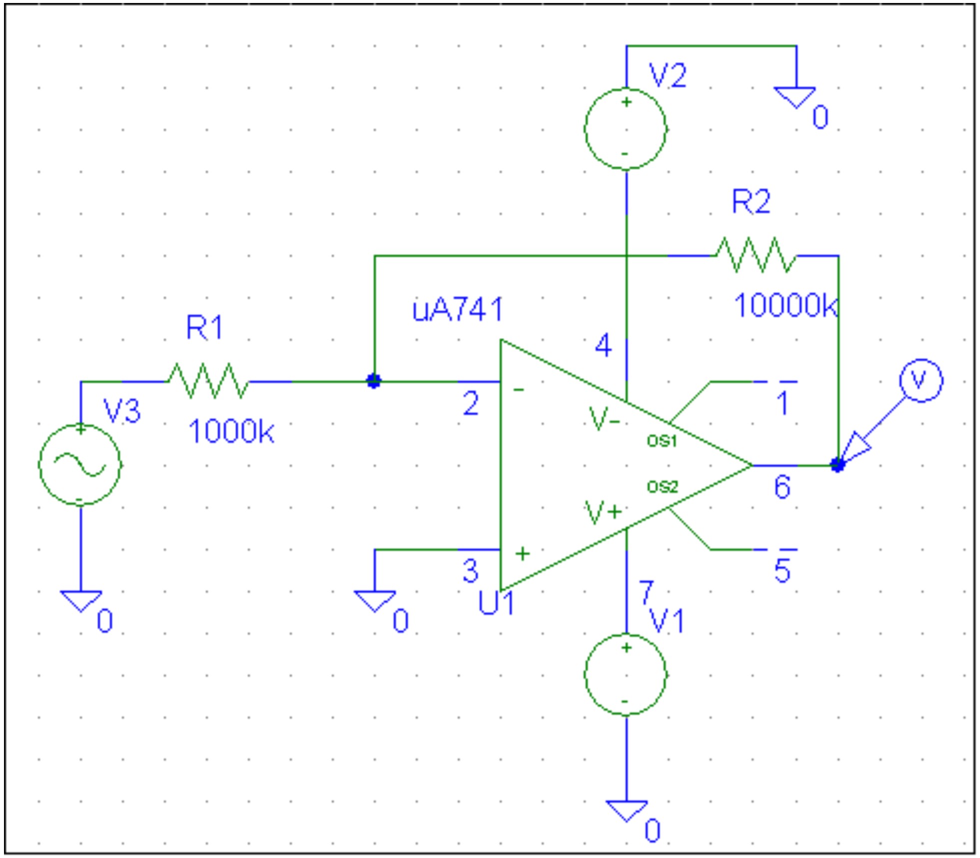
se obtine:

$$V_O = 0$$

# SIMULARI pentru evaluarea erorilor introduse de valoarea nenula a curentului de polarizare a intrarilor ($I_B$)

# SIMULARI pentru evaluarea erorilor introduse de valoarea nenula a curentului de polarizare a intrarilor ($I_B$)

## SIM 2.16: $v_3$ (t), $v_O$ (t) ( fara compensare cu $R_3$ )



$$v_3(t) = V_{AMPL} \sin(2\pi f t)$$

$$V_{AMPL} = 5mV$$

$$f = 1kHz$$

$$I_B = 80nA$$

$$\Delta V_O = -I_{B2} R_3 \left( 1 + \frac{R_2}{R_1} \right) + I_{B1} R_2$$

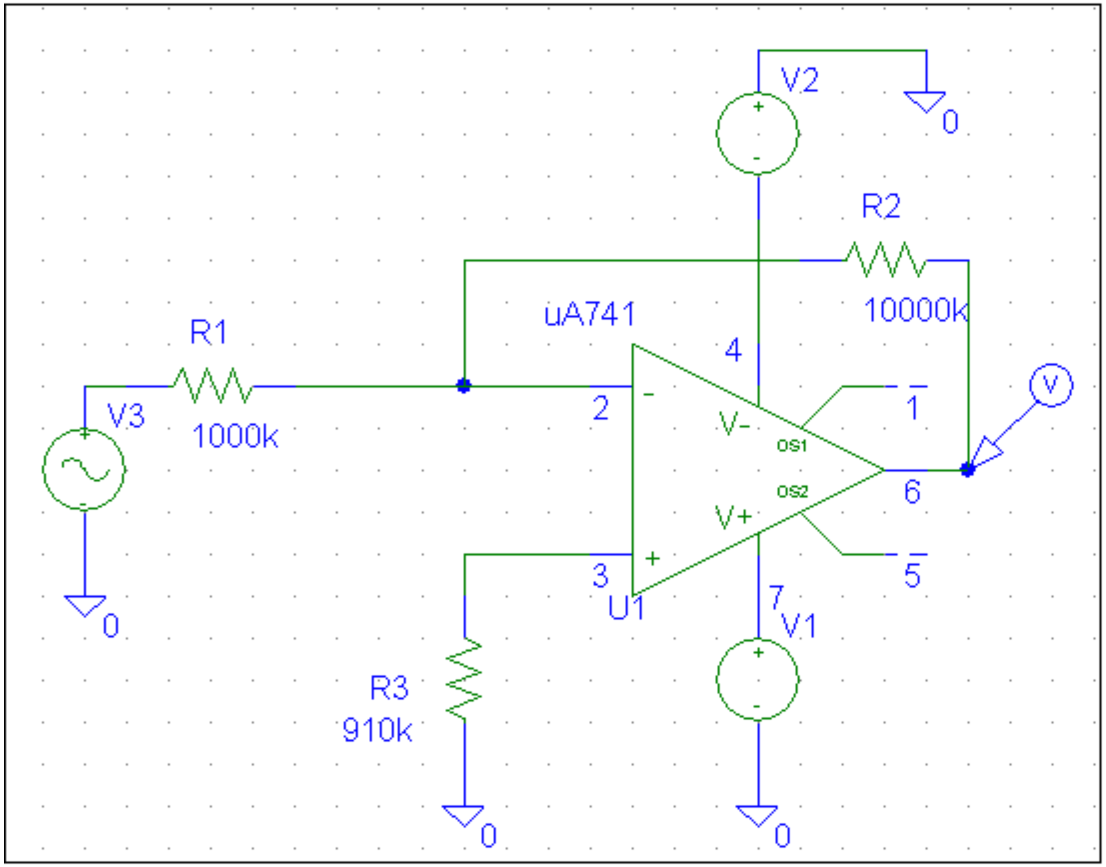
$$R_3 = 0 \Rightarrow \Delta V_O = I_{B1} R_2$$

$$\Delta V_O = 80nA \times 10M\Omega$$

$$\Delta V_O = 800mV$$

# SIMULARI pentru evaluarea erorilor introduse de valoarea nenula a curentului de polarizare a intrarilor ($I_B$)

## SIM 2.17: $v_3$ (t), $v_O$ (t) ( cu compensare folosind $R_3$ )



$$v_3(t) = V_{AMPL} \sin(2\pi f t)$$

$$V_{AMPL} = 5mV$$

$$f = 1kHz$$

$$I_B = 80nA$$

$$\Delta V_O = -I_{B2} R_3 \left( 1 + \frac{R_2}{R_1} \right) + I_{B1} R_2$$

$$R_3 = R_1 // R_2$$

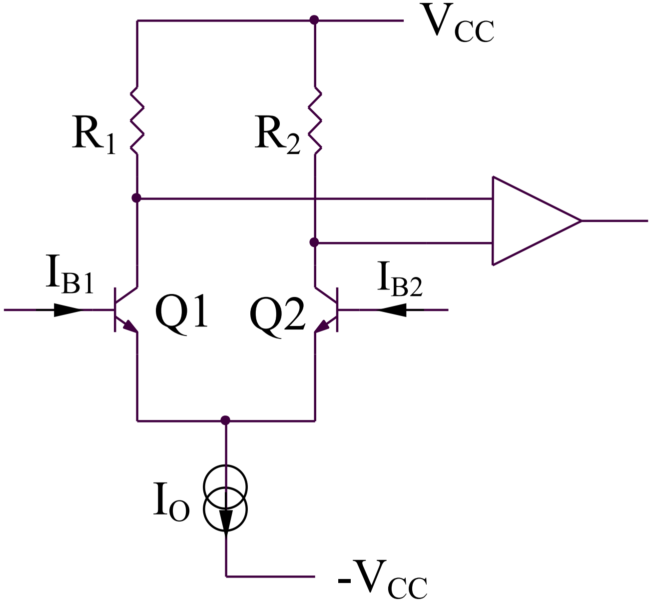
$$R_3 = 1M\Omega // 10M\Omega$$

$$R_3 \cong 910k\Omega$$

$$\Rightarrow \Delta V_O = 0$$

# 2.4. Deviatii de la idealitate si limitari ale AO real

## 2.4.3. Curentul de offset (decalaj) de intrare ($I_{IO}$)



$$I_{IO} = I_{B1} - I_{B2}$$

# 2.4. Deviatii de la idealitate si limitari ale AO real

## 2.4.4. Domeniul tensiunii de intrare de mod comun [$v_{ICmin}$ $v_{ICmin}$]

Domeniul tensiunii de intrare de mod comun este reprezentat de intervalul maxim de variatie al tensiunii de intrare de mod comun pentru care circuitul functioneaza corect.

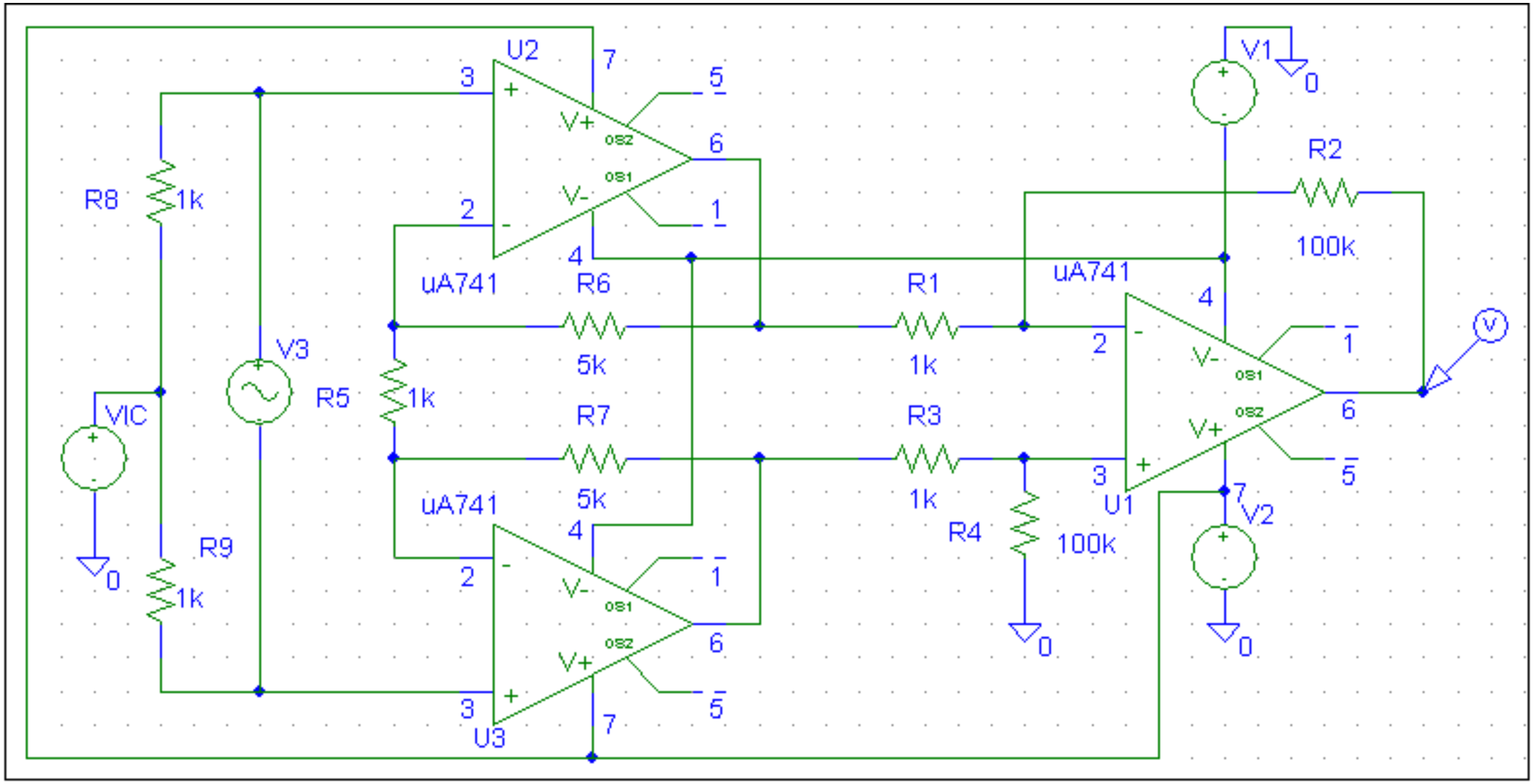
# SIMULARI pentru evaluarea limitarilor introduse de [$v_{ICmin}$ $v_{ICmin}$]

# 2.4. Deviatii de la idealitate si limitari ale AO real

## 2.4.4. Domeniul tensiunii de intrare de mod comun [$v_{ICmin}$ $v_{ICmin}$]

## SIMULARI pentru evaluarea limitarilor introduse de [$v_{ICmin}$ $v_{ICmin}$]

## SIM 2.18: $v_O$ (t) – pentru $v_{ICmin} < v_{IC} < v_{ICmax}$



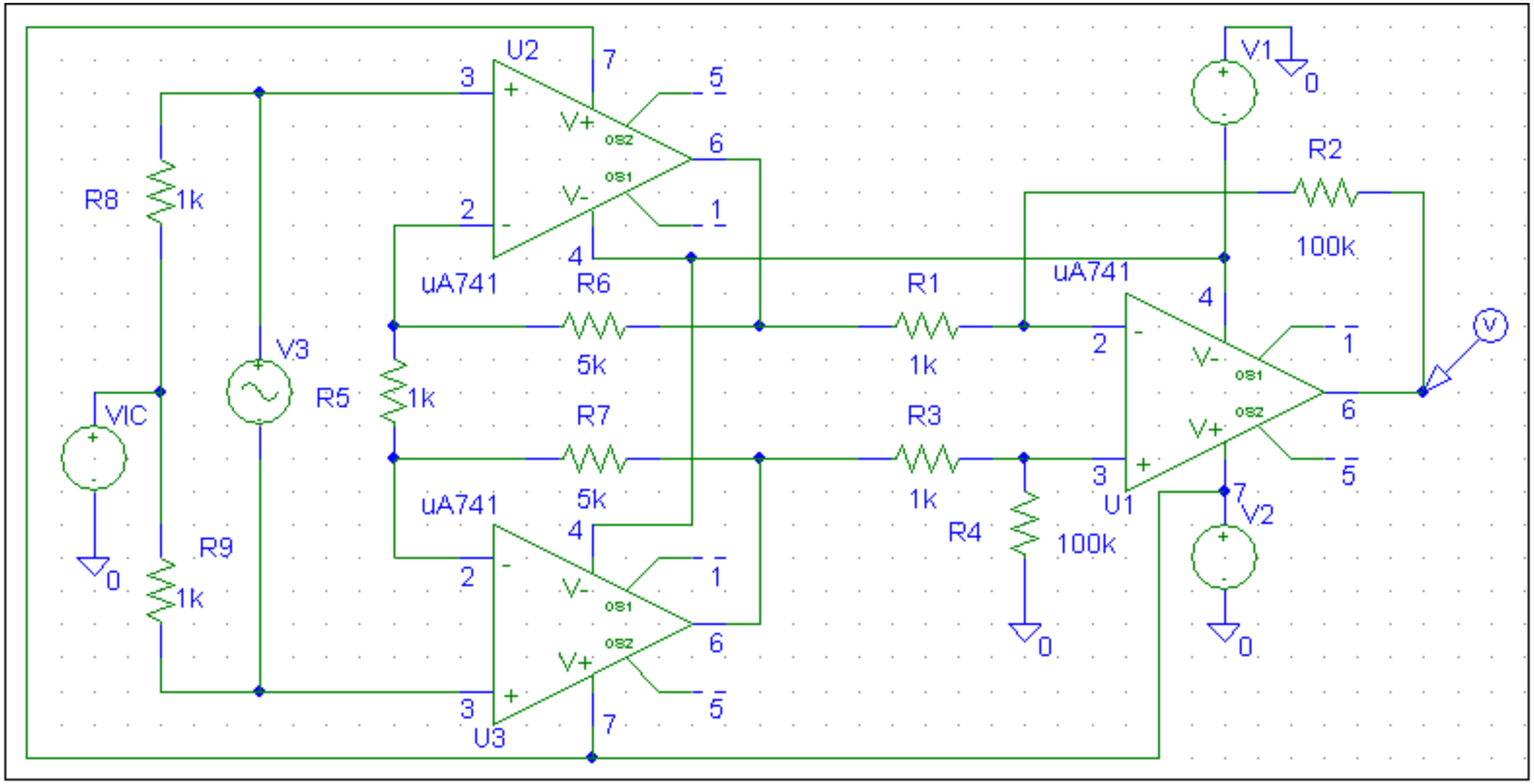
$$v_3(t) = V_{AMPL}\sin(2\pi f t) \qquad V_{AMPL} = 1mV ; f = 100Hz; v_{IC} = 0 \qquad A = \frac{v_O}{v_3} = 1100$$

# 2.4. Deviatii de la idealitate si limitari ale AO real

## 2.4.4. Domeniul tensiunii de intrare de mod comun [$v_{ICmin}$ $v_{ICmin}$]

## SIMULARI pentru evaluarea limitarilor introduse de [$v_{ICmin}$ $v_{ICmin}$]

### SIM 2.19: $v_O$ (t) – pentru $v_{IC} > v_{ICmax}$



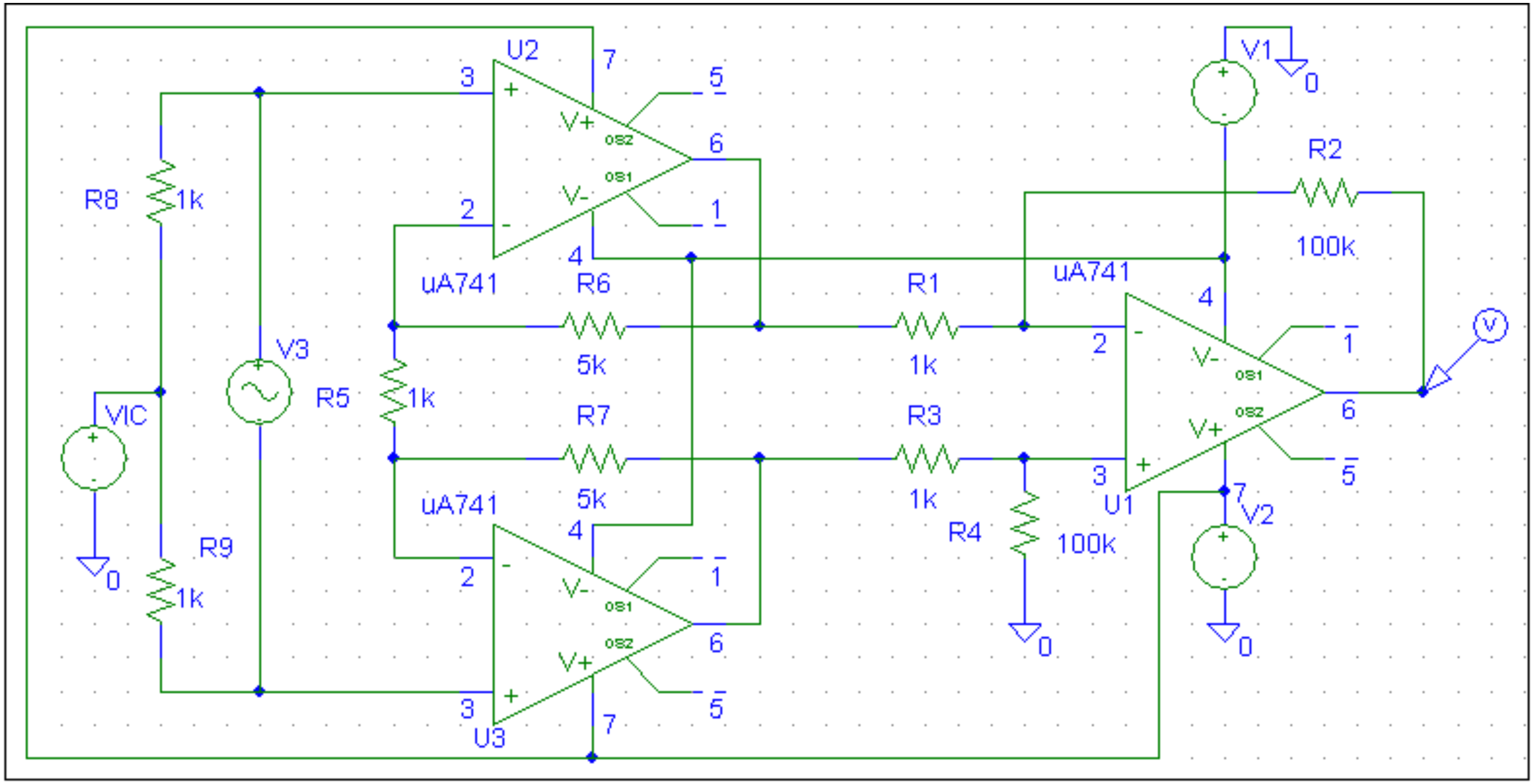
$$v_3(t)=V_{AMPL}\sin(2\pi f\, t) \quad V_{AMPL}=1mV\,;\, f=100Hz; v_{IC}=9V \quad A=\frac{v_O}{v_3}=1100$$

# 2.4. Deviatii de la idealitate si limitari ale AO real

## 2.4.4. Domeniul tensiunii de intrare de mod comun [$v_{ICmin}$ $v_{ICmin}$]

### SIMULARI pentru evaluarea limitarilor introduse de [$v_{ICmin}$ $v_{ICmin}$]

### SIM 2.20: $v_O$ (t) – pentru $v_{IC} < v_{ICmin}$



$$v_3(t) = V_{AMPL}\sin(2\pi f t) \quad V_{AMPL} = 1mV;\, f = 100\,Hz;\, v_{IC} = -9V \quad A = \frac{v_O}{v_3} = 1100$$

# 2.4. Deviatii de la idealitate si limitari ale AO real

## 2.4.5. Excursia maxima a tensiunii de iesire $[v_{Omin}, v_{Omax}]$

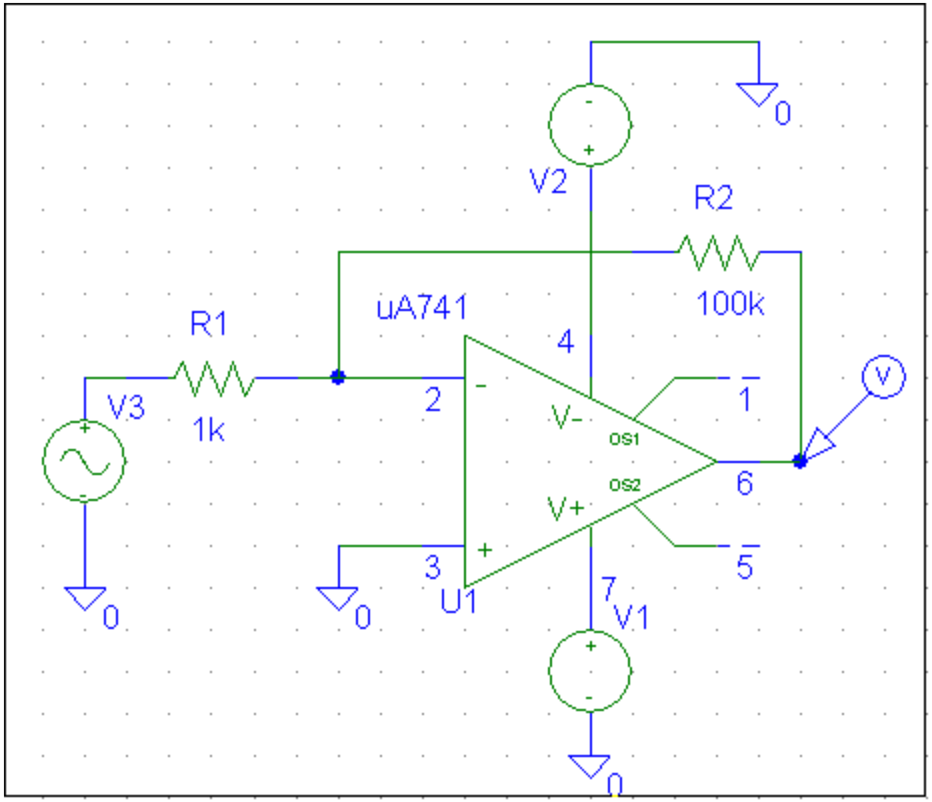
Reprezinta limitele (minima si maxima) intre care poate evolua tensiunea de iesire a AO.

Este corelata cu tensiunile de alimentare ale AO, fiind influentata de configuratia etajului de iesire al acestuia.

# SIMULARI pentru evaluarea excursiei maxime a tensiunii de iesire [$v_{Omin}$, $v_{Omax}$ ]

# SIMULARI pentru evaluarea excursiei maxime a tensiunii de iesire [$v_{Omin}$, $v_{Omax}$ ]

## SIM 2.21: $v_3$ (t), $v_O$ (t)



$$v_3(t) = V_{AMPL} \sin(2\pi\, f\, t)$$

$$V_{AMPL} = 200mV$$

$$f = 1kHz$$

$$V_1 = 9V ; V_2 = -9V$$

$$v_O(t) = -\frac{R_2}{R_1} v_3(t) = -100 v_3(t)$$

$$v_O(t) = -20V \sin(2\pi\, f\, t)$$

# 2.4. Deviatii de la idealitate si limitari ale AO real

## 2.4.6. Curentul maxim de iesire al AO ( $I_{Omax}$ )

Reprezinta valoarea maxima a curentului furnizat de iesirea AO.

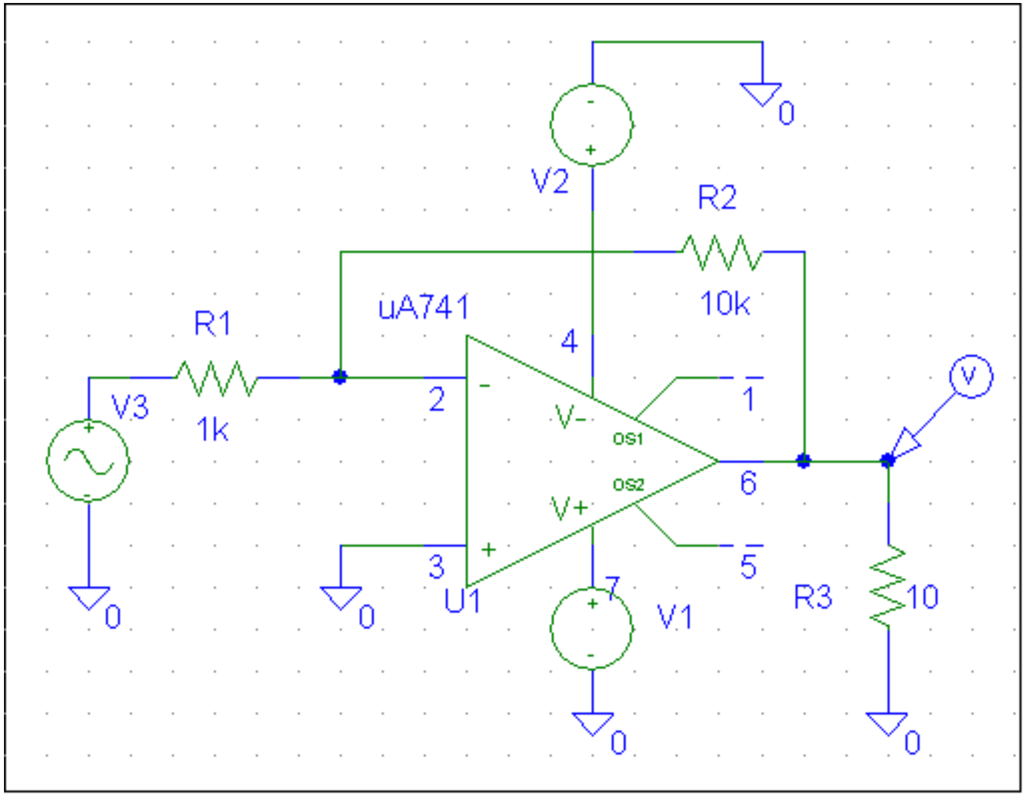
# SIMULARI pentru evaluarea curentului maxim de iesire ( $I_{Omax}$ )

# 2.4. Deviatii de la idealitate si limitari ale AO real

## 2.4.6. Curentul maxim de iesire al AO ( $I_{Omax}$ )

### SIMULARI pentru evaluarea curentului maxim de iesire ( $I_{Omax}$ )

### SIM 2.22: $v_3$ (t), $v_O$ (t)



$$v_3(t) = V_{AMPL} \sin(2\pi f t)$$

$$V_{AMPL} = 100mV$$

$$v_O(t) = -\frac{R_2}{R_1} v_3(t) = -10 v_3(t)$$

$$v_O(t) = -1V \sin(2\pi f t)$$

$$i_O(t) = \frac{v_O(t)}{R_3}$$

$$i_O(t) = -100mA \sin(2\pi f t)$$

# 2.4. Deviatii de la idealitate si limitari ale AO real

## 2.4.7. Factorul de rejectie a tensiunii de mod comun (CMRR)

Caracterizeaza capacitatea amplificatorului operational de a amplifica semnalele de mod diferential si de a rejecta semnalele de mod comun.

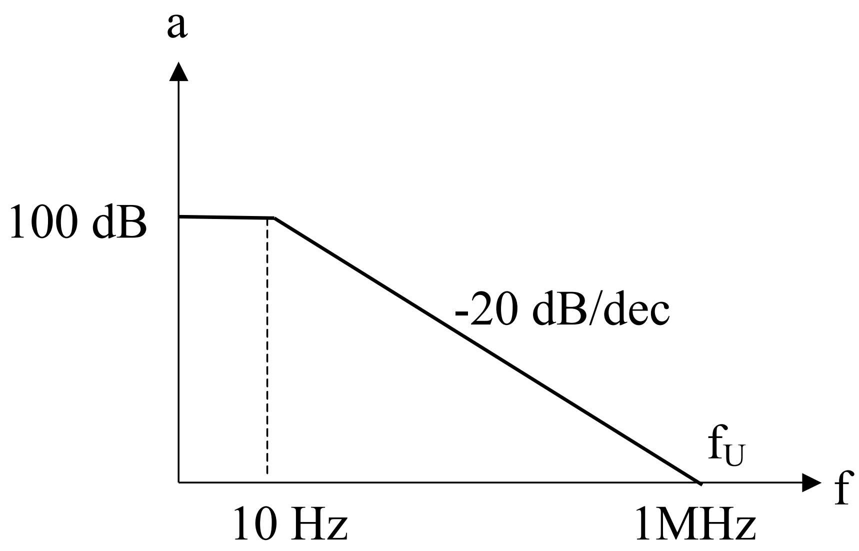
## 2.4.8. Factorul de rejectie a tensiunii de alimentare (PSRR)

Caracterizeaza capacitatea amplificatorului operational de a rejecta variatiile tensiunii de alimentare.

# 2.4. Deviatii de la idealitate si limitari ale AO real

## 2.4.9. Frecventa de amplificare unitara ( $f_U$ )

Reprezinta frecventa pentru care amplificarea in bucla deschisa a AO devine unitara.

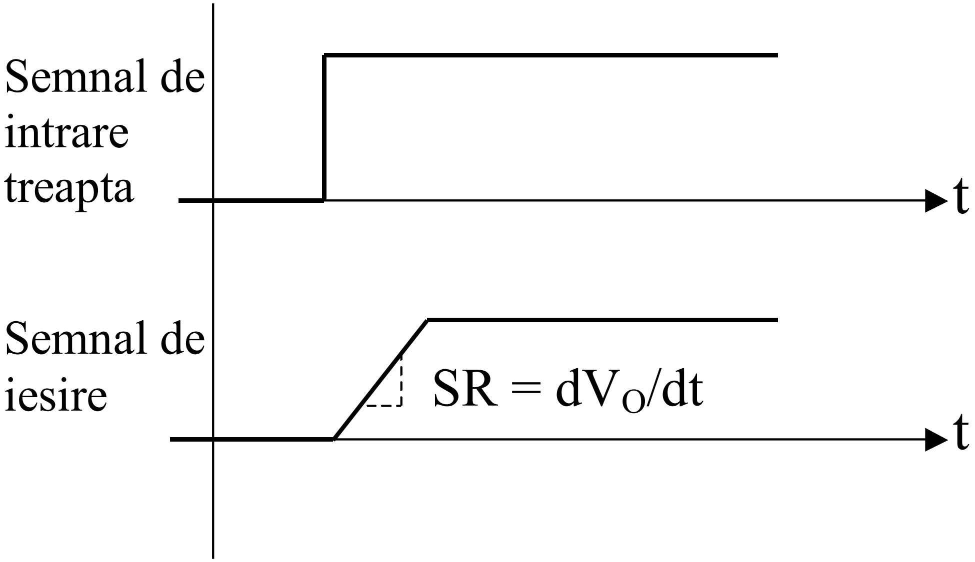


$f_U$ – in domeniul 1MHz – 100MHz

# 2.4. Deviatii de la idealitate si limitari ale AO real

## 2.4.10. Slew-rate-ul (SR)

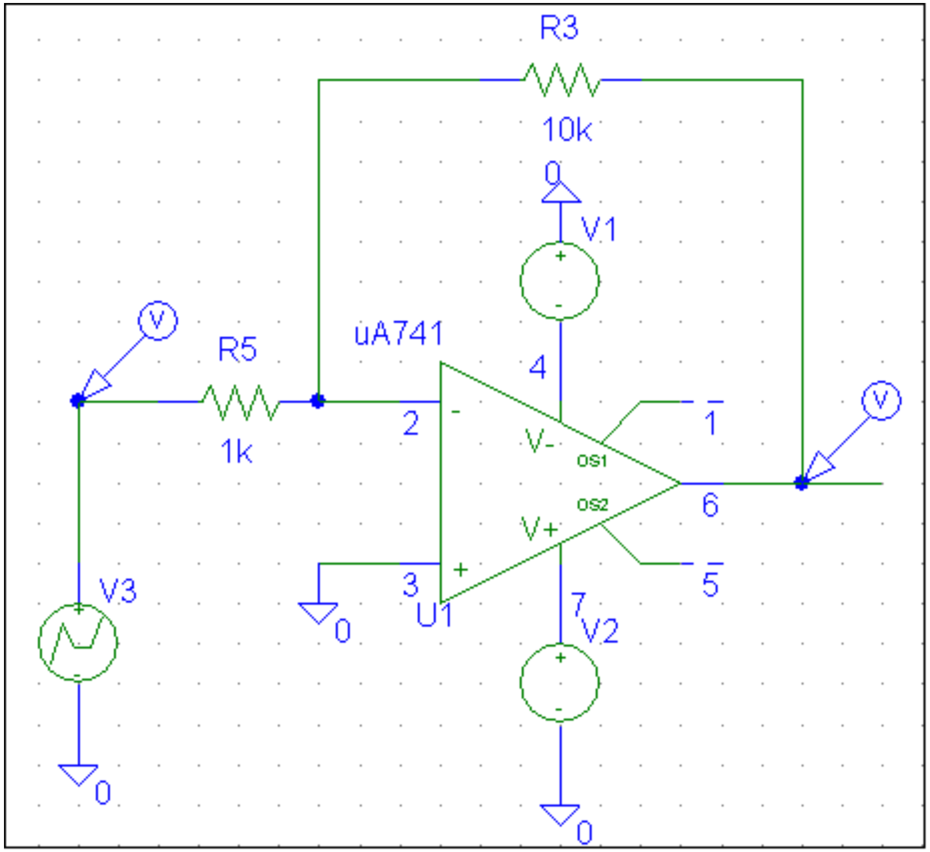
Reprezinta panta maxima a raspunsului tranzitoriu pentru un semnal de intrare de tip treapta.



# SIMULARI pentru evaluarea erorilor introduse de valoarea finita a slew-rate-ului (SR) unui AO

# SIMULARI pentru evaluarea erorilor introduse de valoarea finita a slew-rate-ului (SR) unui AO

## SIM 2.23: $v_3$ (t), $v_O$ (t)

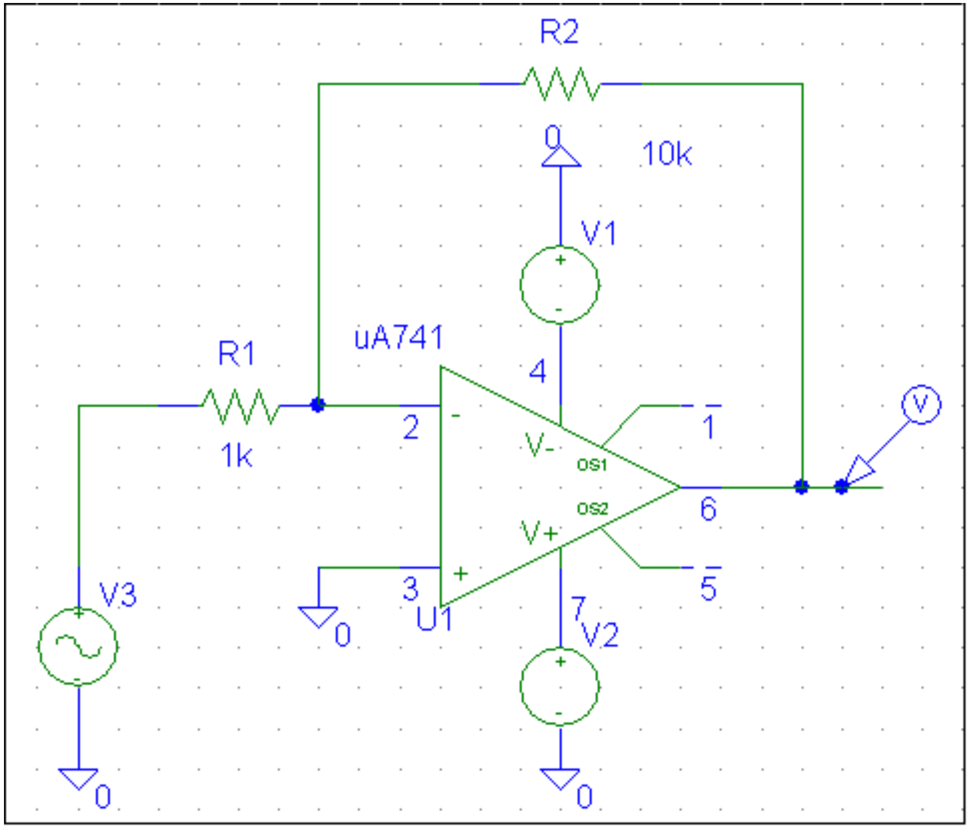


$v_3$ **- semnal dreptunghiular**

$$SR = \frac{dV_O}{dt} = \frac{10V}{20\mu s} = 0{,}5V/\mu s$$

# SIMULARI pentru evaluarea erorilor introduse de valoarea finita a slew-rate-ului (SR) unui AO

## SIM 2.24: $v_3$ (t), $v_O$ (t)



$$v_3(t) = V_{AMPL}\,\sin(2\pi f t)$$

$$V_{AMPL} = 1V$$

$$f = 100kHz$$

$$v_O = -\frac{R_2}{R_1} V_{AMPL}\,\sin(2\pi f t)$$

$$\frac{dv_O(t)}{dt} = 2\pi f V_{AMPL}\left(-\frac{R_2}{R_1}\right)\cos(2\pi f t)$$

$$\left.\frac{dv_O(t)}{dt}\right|_{max} = 2\pi f V_{AMPL}\frac{R_2}{R_1}$$

$$\left.\frac{dv_O(t)}{dt}\right|_{max} = 6{,}28V/\mu s > SR \cong 0{,}5V/\mu s$$