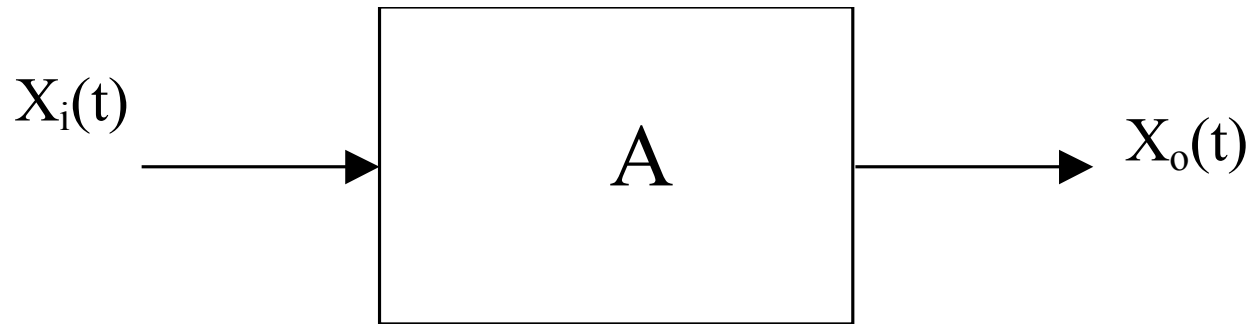


# **Capitolul 2**

## **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

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

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

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

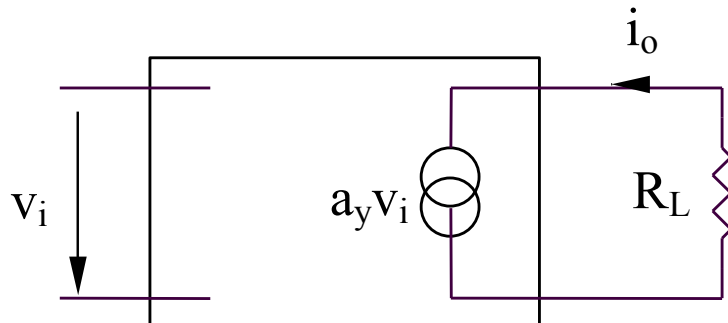
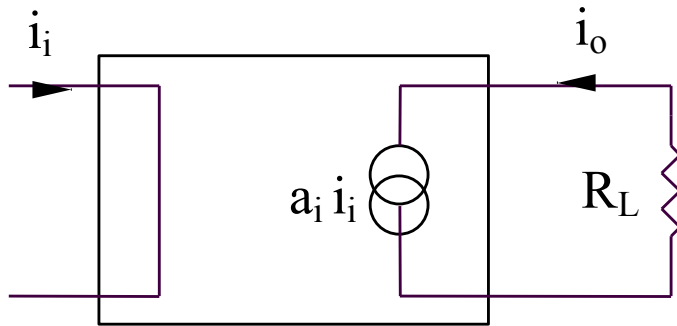
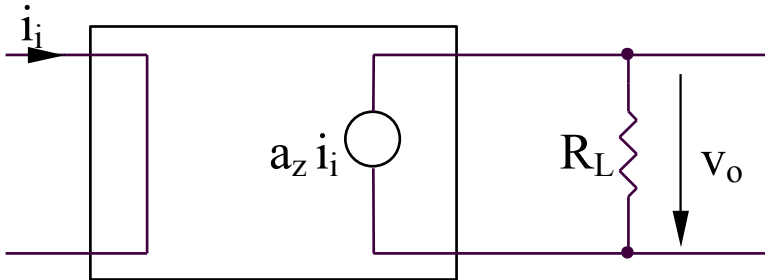
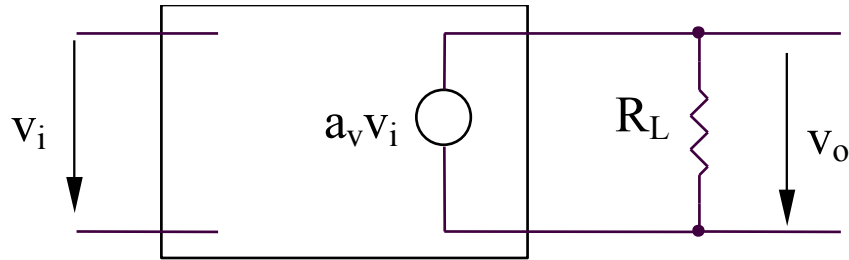
$$A_z = \frac{v_O}{i_I}$$

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

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

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

## 2.1.2. Amplificatoare ideale



### Amplificatorul de tensiune

$$v_O = a_v v_I \quad i_I = 0; P_i = 0$$
$$R_i \rightarrow \infty; R_o = 0$$

### Amplificatorul trans-impedanta

$$v_O = a_z i_I \quad v_I = 0; P_i = 0$$
$$R_i = 0; R_o = 0$$

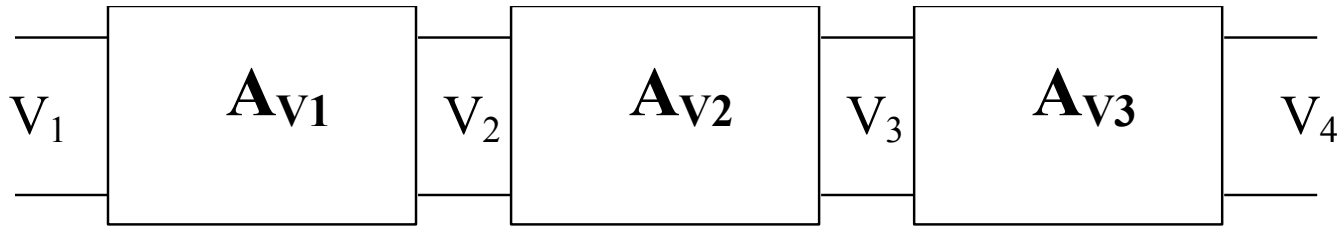
### Amplificatorul de curent

$$i_O = a_i i_I \quad v_I = 0; P_i = 0$$
$$R_i = 0; R_o \rightarrow \infty$$

### Amplificatorul trans-admitanta

$$i_O = a_y v_I \quad i_I = 0; P_i = 0$$
$$R_i \rightarrow \infty; R_o \rightarrow \infty$$

### 2.1.3. Cuplarea amplificatoarelor

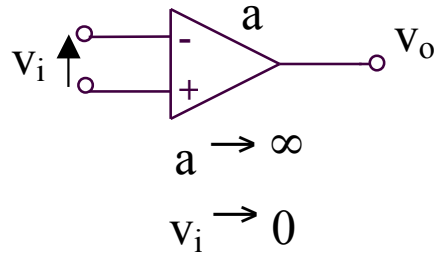


$$A_V = \frac{V_4}{V_1} = A_{V1}A_{V2}A_{V3}$$

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

## **2.2. Aplicatii ale amplificatoarelor operationale**

## 2.2. Aplicatii ale amplificatoarelor operationale



### **AO ideal**

- impedanta de intrare infinita
- impedanta de iesire nula
- amplificare in tensiune infinita
- banda de frecventa infinita (raspuns instantaneu)
- tensiune de iesire nula pentru tensiune de intrare nula
- **diferenta de potential nula intre cele doua intrari**
- **curenti nuli de intrare**

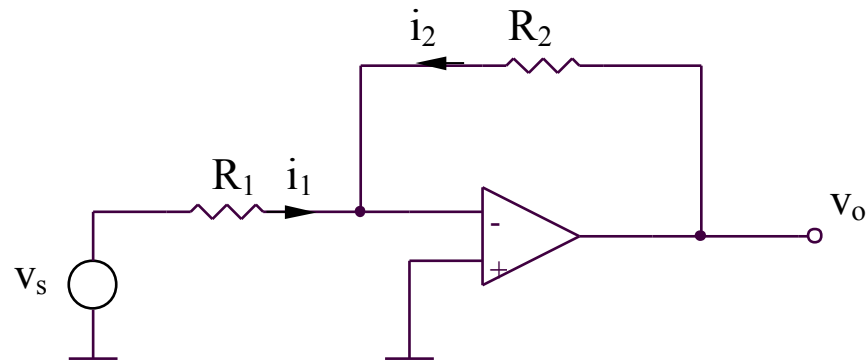
### **AO real:**

- impedanta de intrare foarte mare
- impedanta de iesire mica
- amplificare in tensiune foarte mare



## 2.2. Aplicatii ale amplificatoarelor operationale

### 2.2.1. Amplificatorul inversor



$$i_1 = -i_2$$

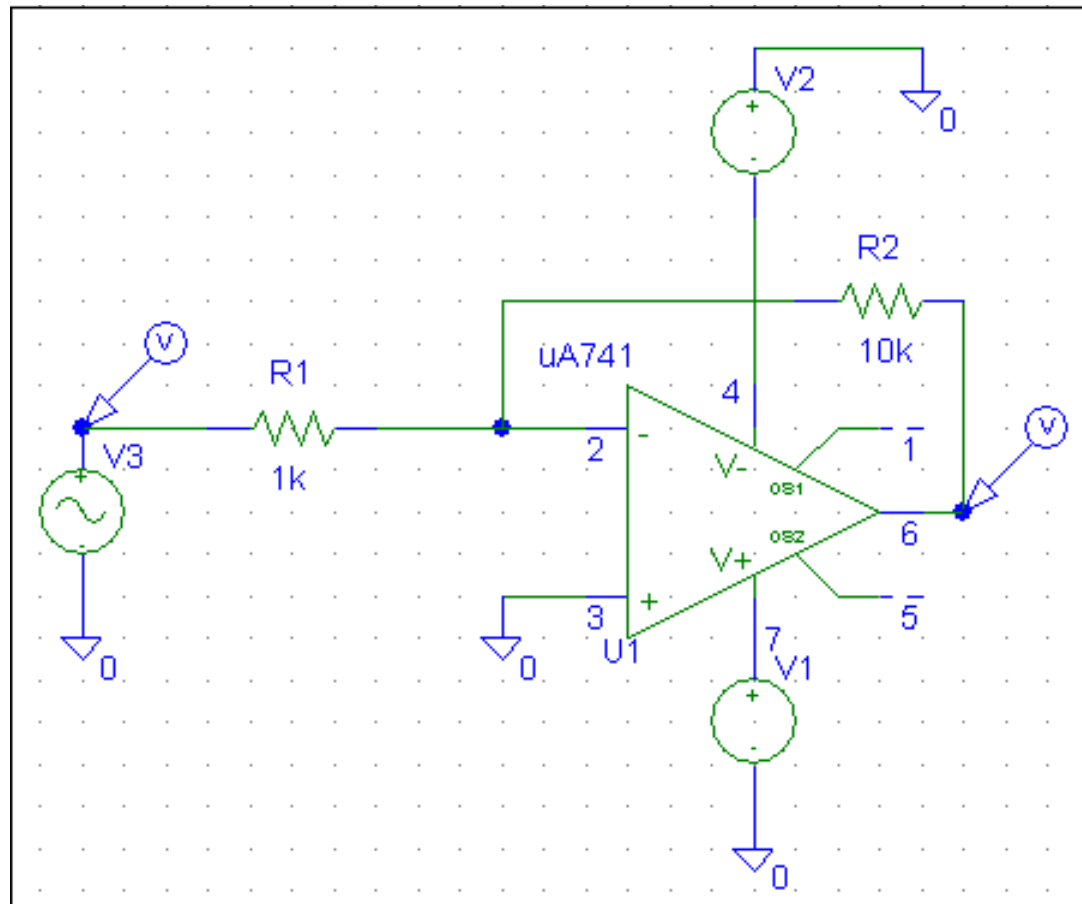
$$\frac{v_s}{R_1} = -\frac{v_o}{R_2}$$

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

## **SIMULARI pentru amplificatorul inversor**

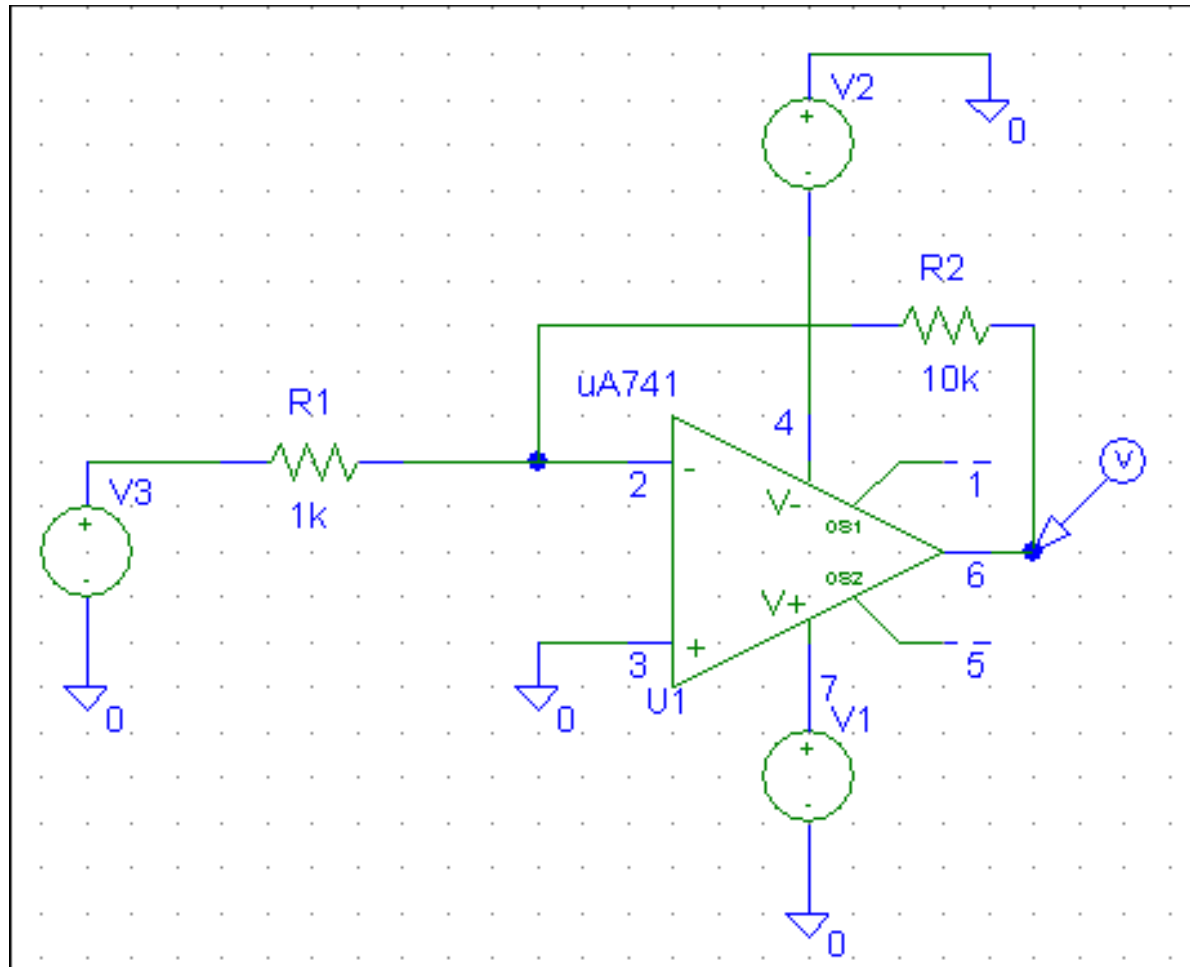
# SIMULARI pentru amplificatorul inversor

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

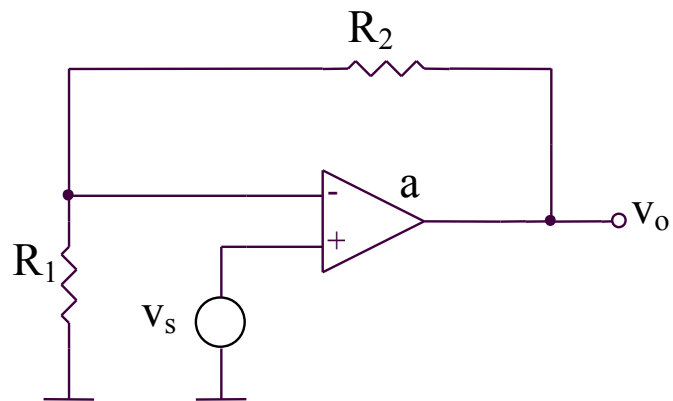


# SIMULARI pentru amplificatorul inversor

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



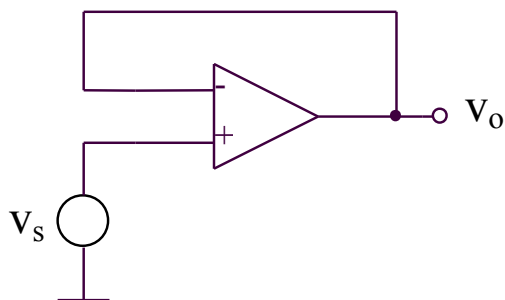
## 2.2.2. Amplificatorul neinversor



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

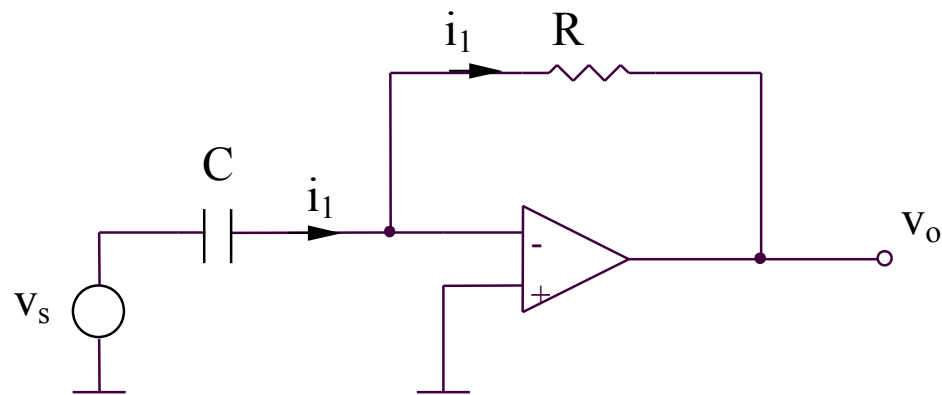
$$A = \frac{v_o}{v_s} = 1 + \frac{R_2}{R_1}$$

## 2.2.3. Circuitul repetor



$$v_o = v_s$$

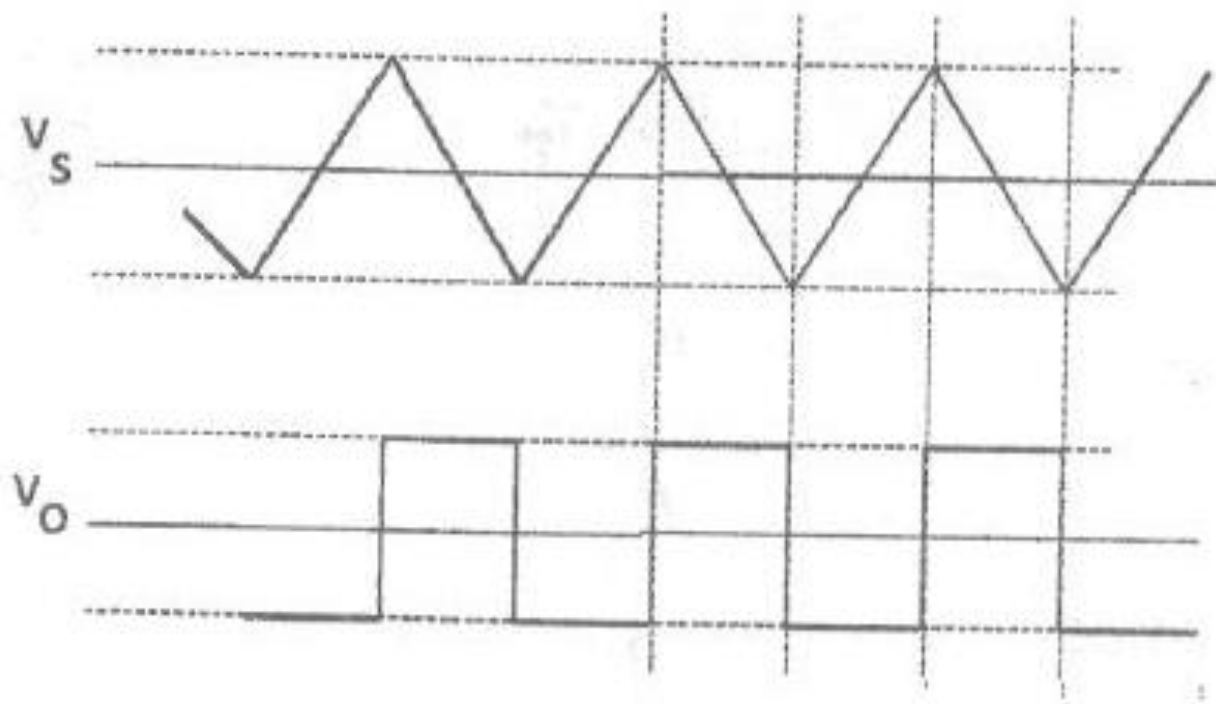
## 2.2.4. Circuitul de derivare



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

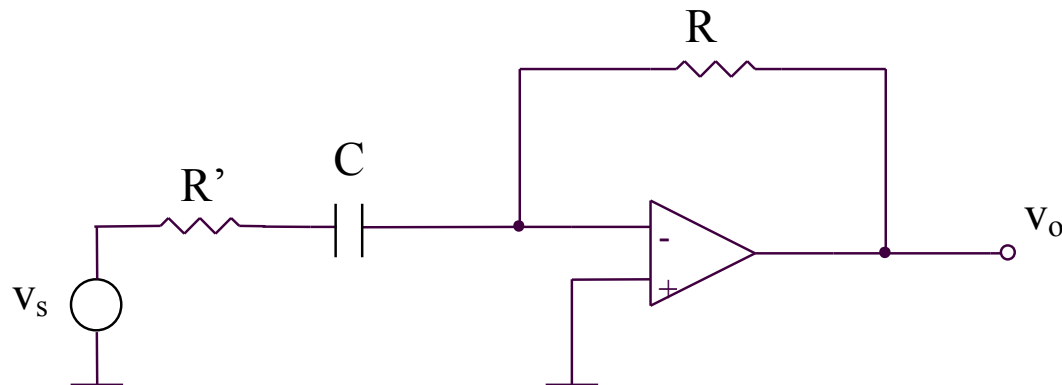
$$v_o = -Ri_1 = -RC \frac{dv_s}{dt}$$

## 2.2.4. Circuitul de derivare

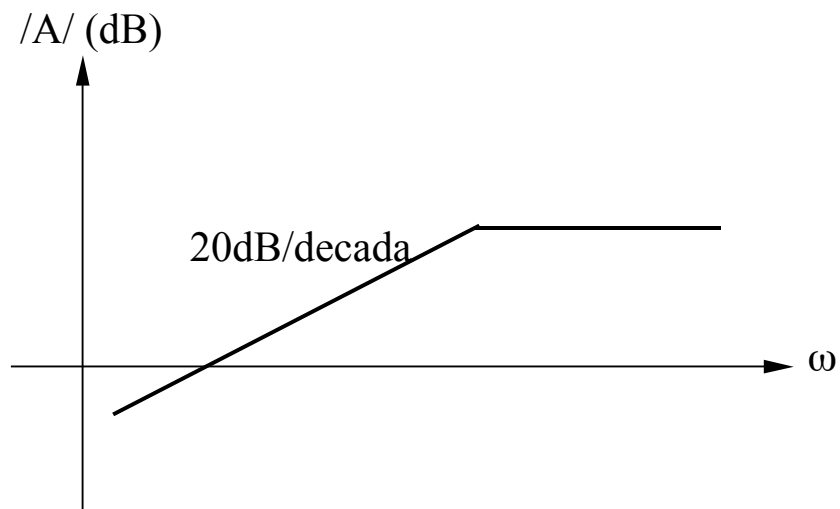


## 2.2.4. Circuitul de derivare

Introducerea  $R'$  – pentru cresterea stabilitatii

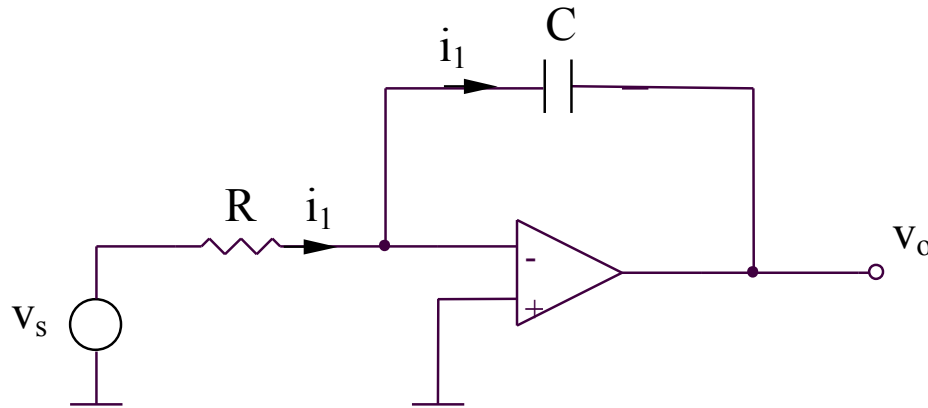


$$A(j\omega) = -\frac{R}{R' + \frac{1}{j\omega C}} = -\frac{R}{R'} \frac{j\omega R' C}{1 + j\omega R' C}$$





## 2.2.5. Circuitul de integrare

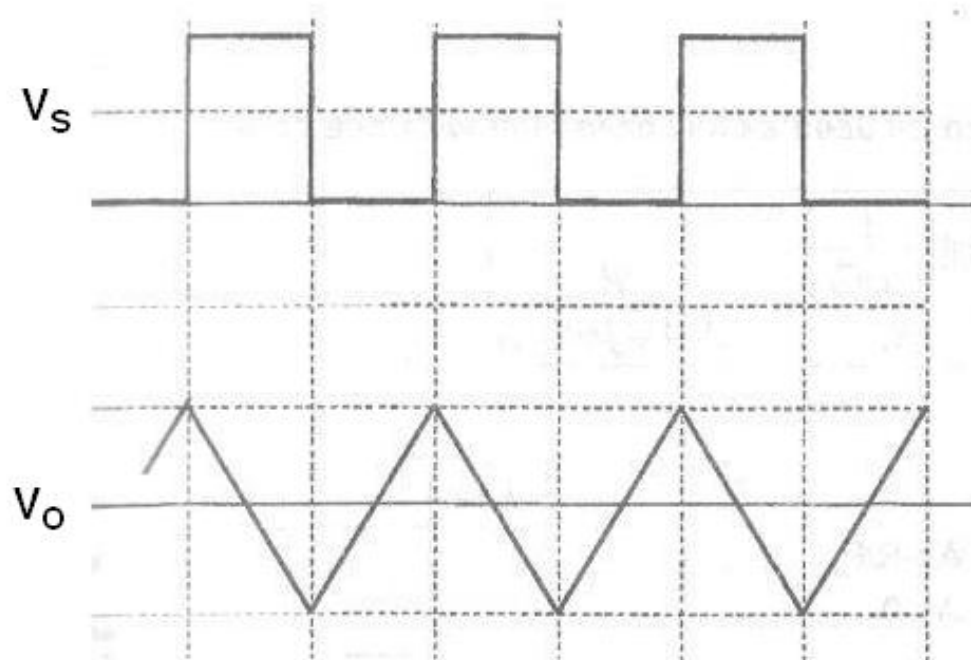


$$i_1 = \frac{v_s(t)}{R}$$

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

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

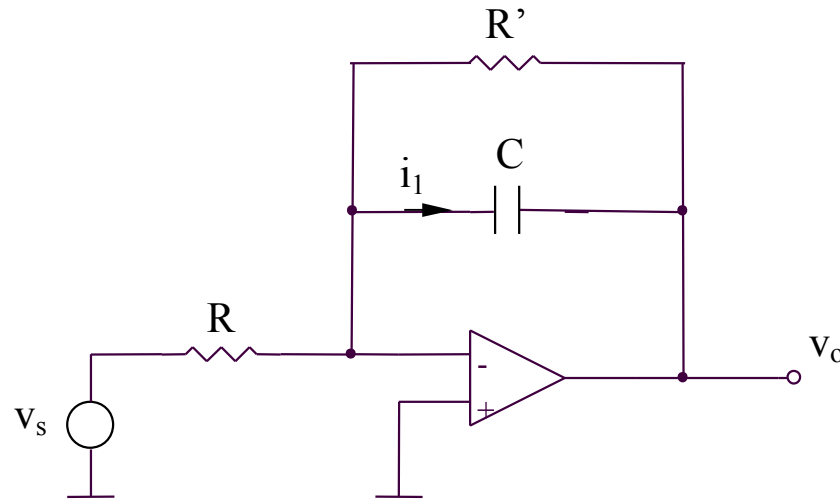
## 2.2.5. Circuitul de integrare



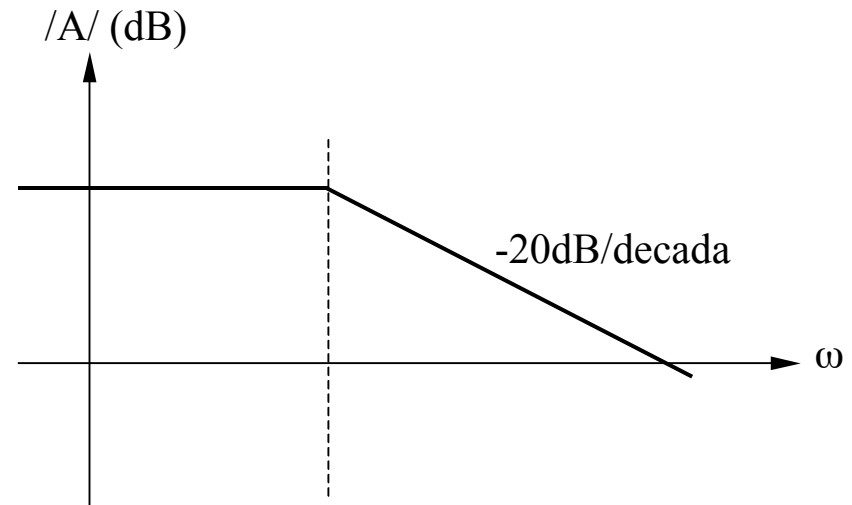
## 2.2.5. Circuitul de integrare

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

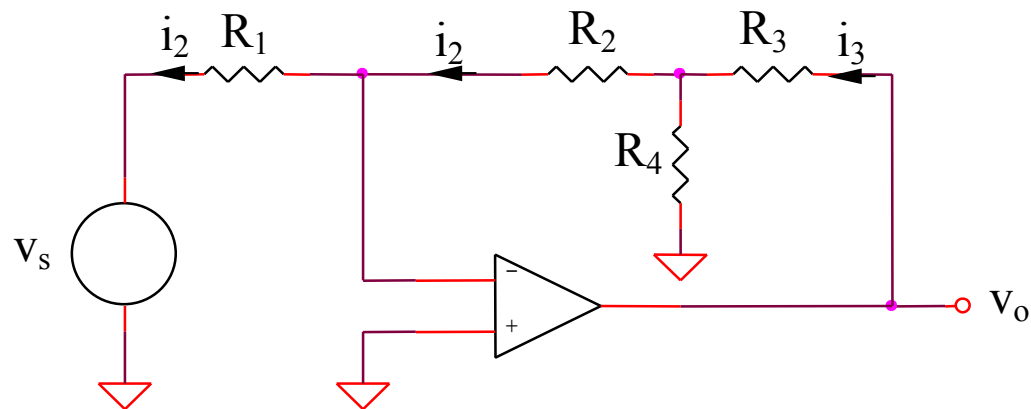
Amplificarea in curent continuu finita,  $A_{cc} = - R' / R$



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



## 2.2.6. Circuit cu amplificare marita



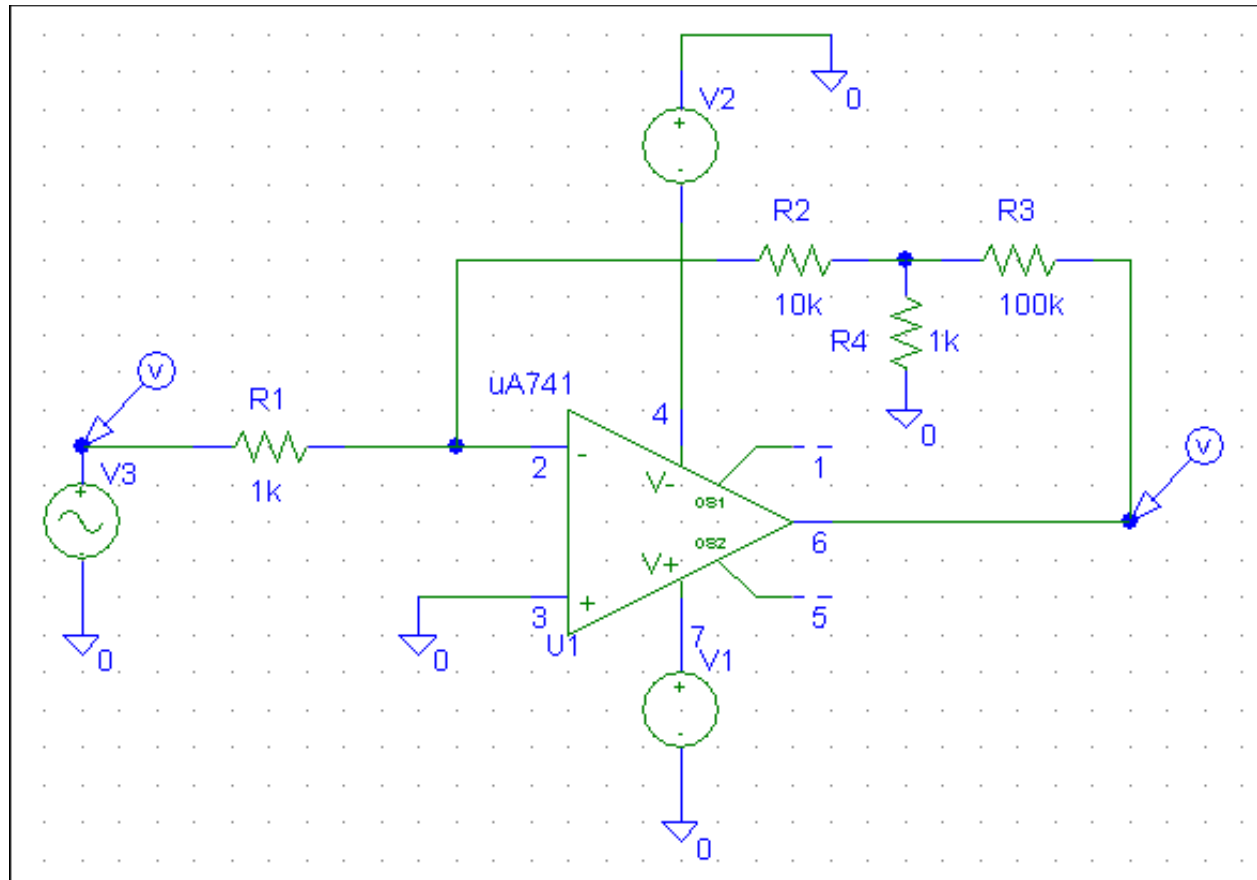
$$A = \frac{v_o}{v_s} = \frac{v_o}{i_3} \frac{i_3}{i_2} \frac{i_2}{v_s}$$

$$A = - \frac{R_2 R_3 + R_2 R_4 + R_3 R_4}{R_1 R_4}$$

## **SIMULARI pentru circuitul cu amplificare marita**

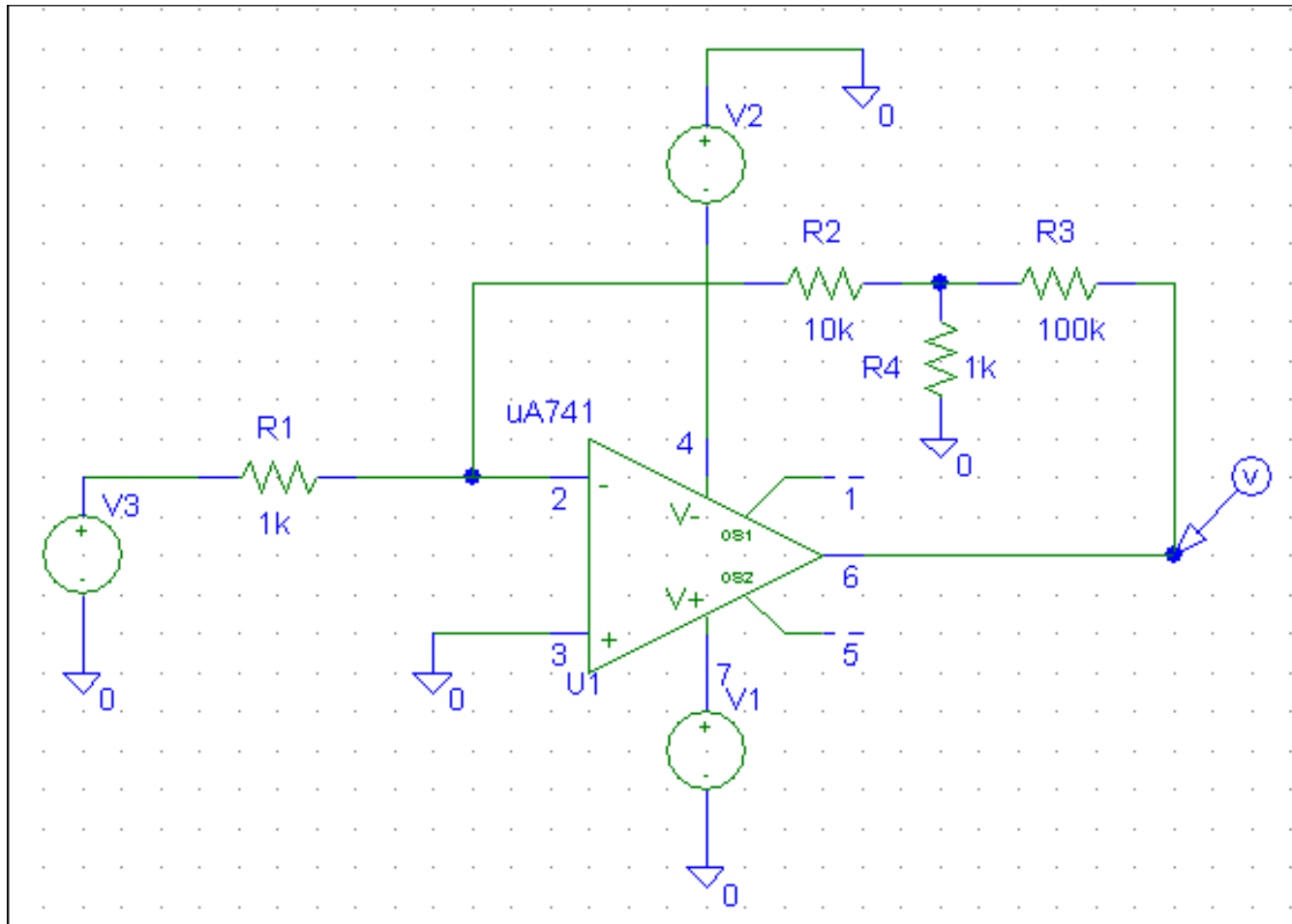
# SIMULARI pentru circuitul cu amplificare marita

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

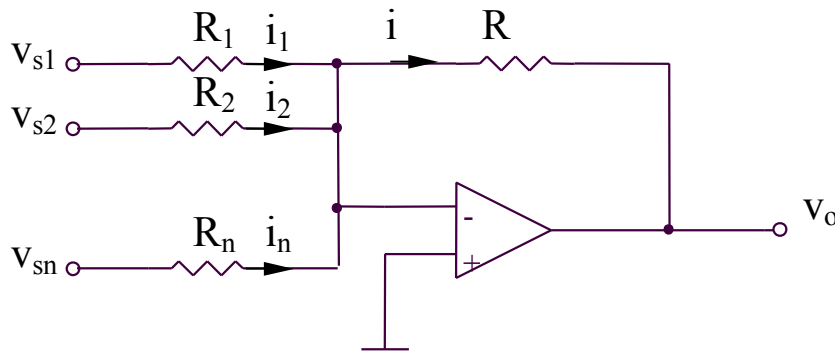


# SIMULARI pentru circuitul cu amplificare marita

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



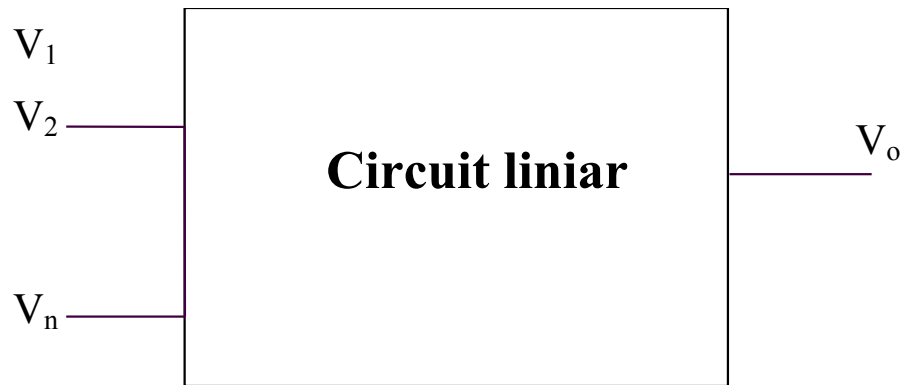
## 2.2.7. Sumatorul inversor



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

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

## Teorema superpozitiei



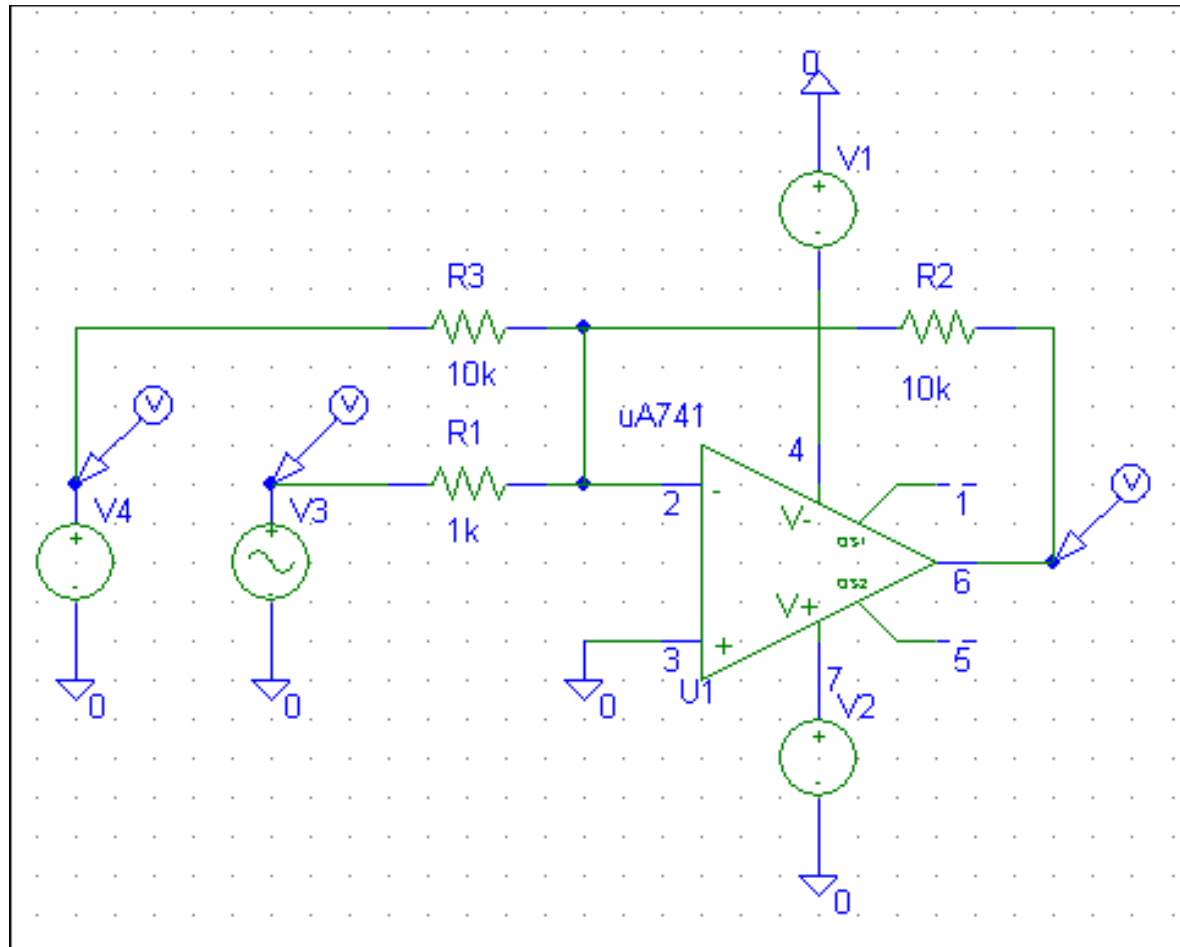
$$V_o = V_o \Big|_{\substack{V_1 \neq 0 \\ V_2 = V_3 = \dots = V_n = 0}} + V_o \Big|_{\substack{V_2 \neq 0 \\ V_1 = V_3 = \dots = V_n = 0}} + \dots + V_o \Big|_{\substack{V_n \neq 0 \\ V_1 = V_2 = \dots = V_{n-1} = 0}}$$



## **SIMULARI pentru sumatorul inversor**

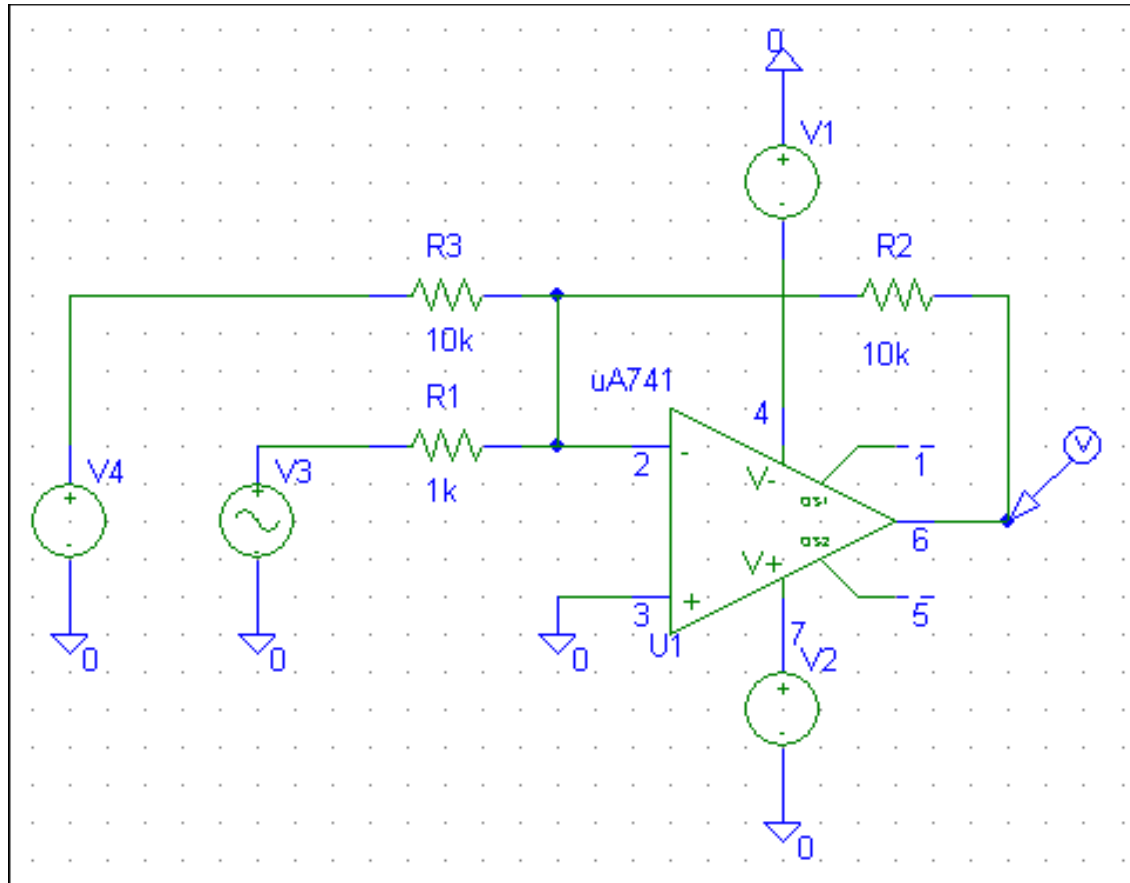
# SIMULARI pentru sumatorul inversor

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

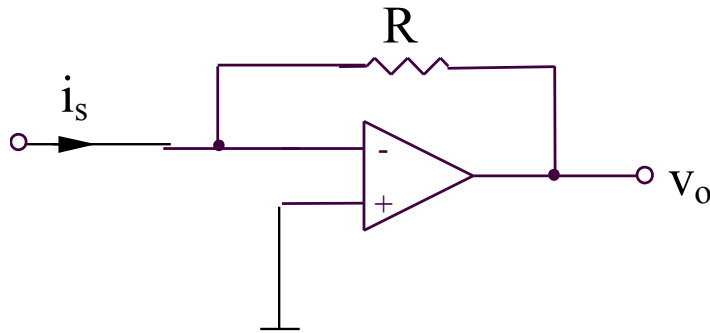


# SIMULARI pentru sumatorul inversor

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

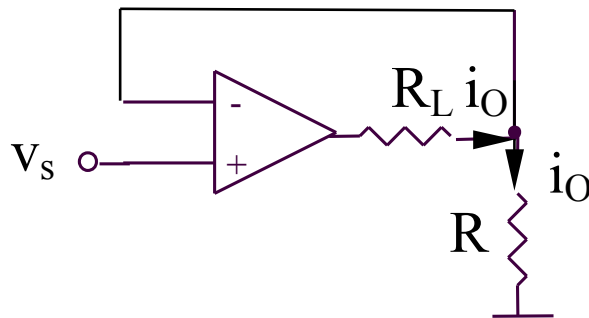


## 2.2.8. Convertorul curent-tensiune



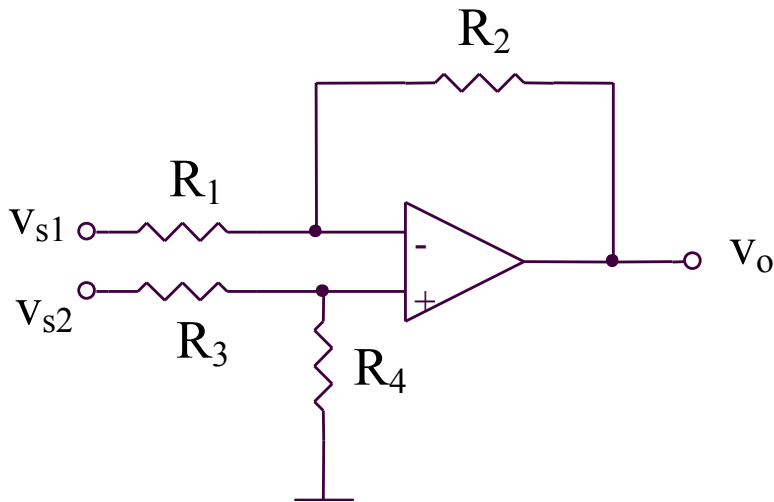
$$v_o = -Ri_s$$

## 2.2.9. Convertorul tensiune-curent



$$i_o = v_s / R$$

## 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:

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

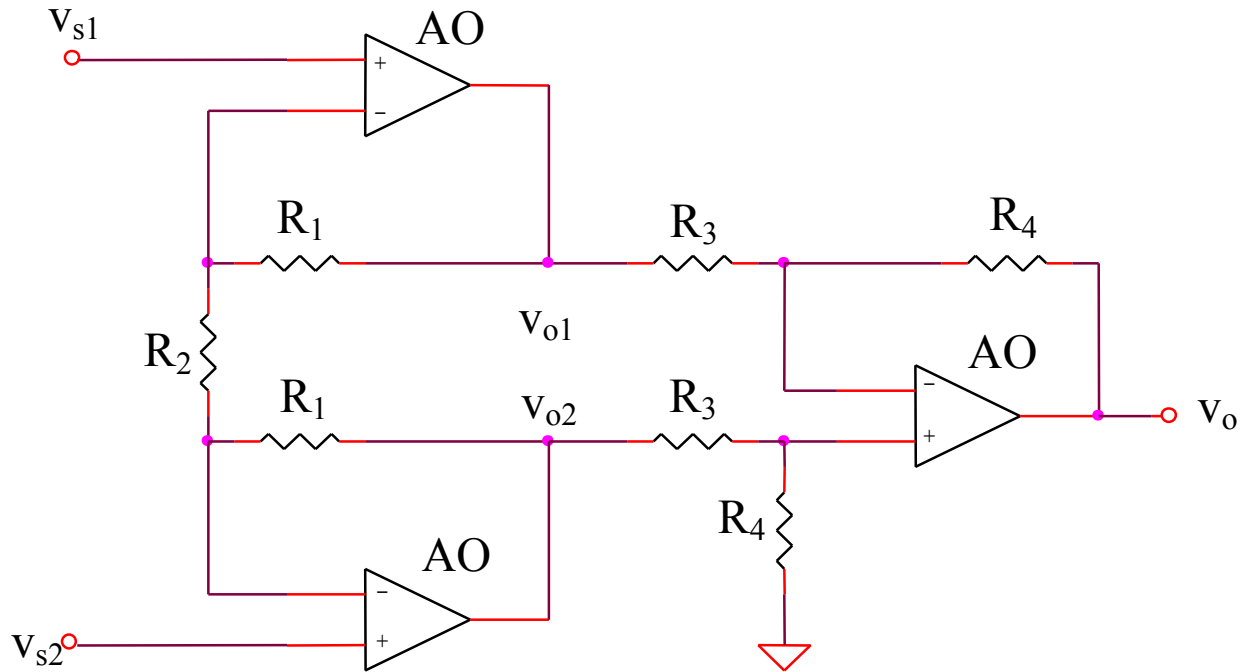
echivalenta cu:

$$R_1 R_4 = R_2 R_3$$

rezultand:

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

## 2.2.11. Circuitul de diferenta (2)

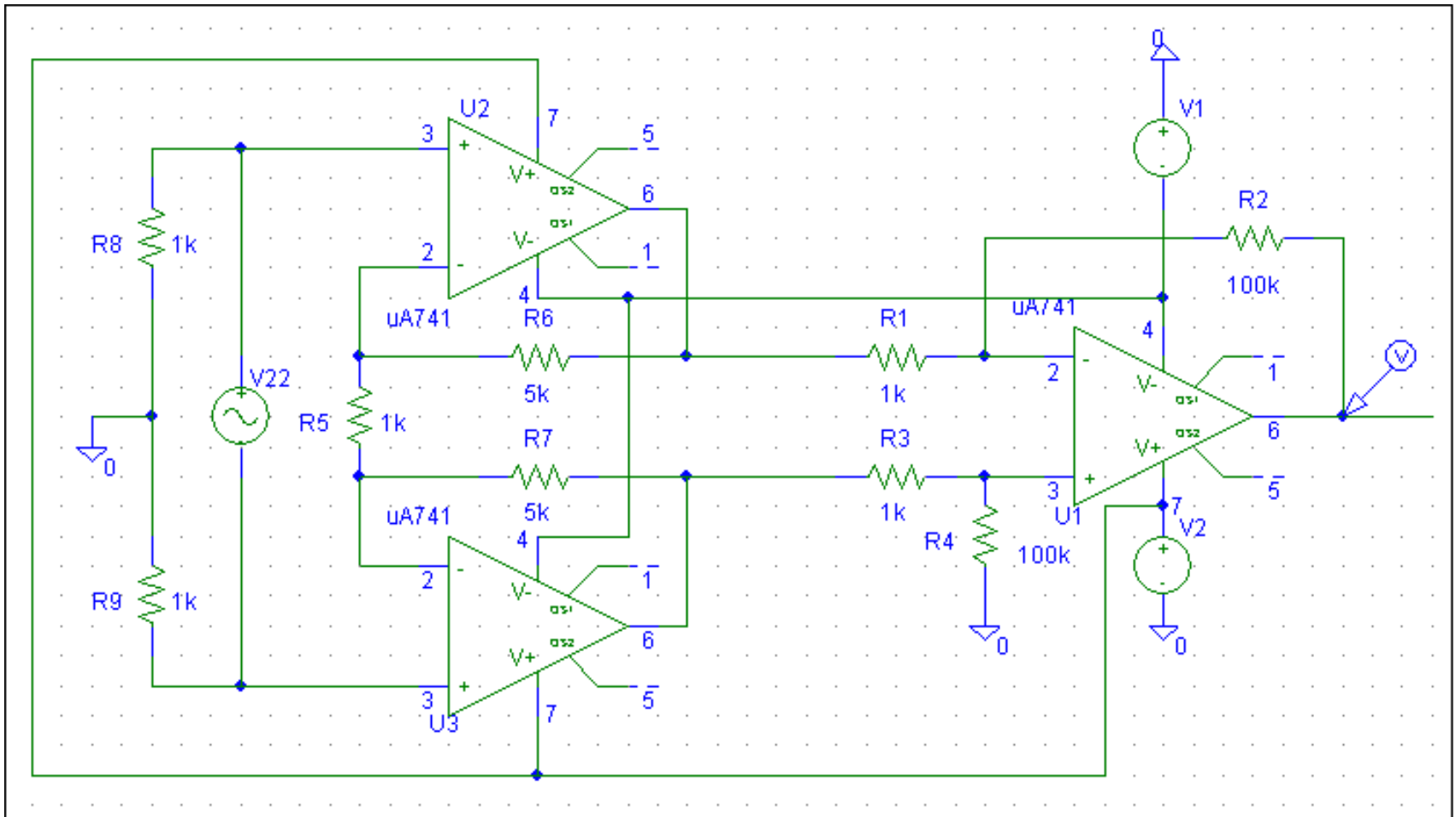


$$\left. \begin{aligned} v_{o1} &= v_{s1} \left( 1 + \frac{R_1}{R_2} \right) - v_{s2} \frac{R_1}{R_2} \\ v_{o2} &= v_{s2} \left( 1 + \frac{R_1}{R_2} \right) - v_{s1} \frac{R_1}{R_2} \\ v_o &= \frac{R_4}{R_3} (v_{o2} - v_{o1}) \end{aligned} \right\} \Rightarrow A = \frac{v_o}{v_{s2} - v_{s1}} = \left(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

## SIMULARI pentru circuitul de diferenta (2)

# SIMULARI pentru circuitul de diferenta (2)

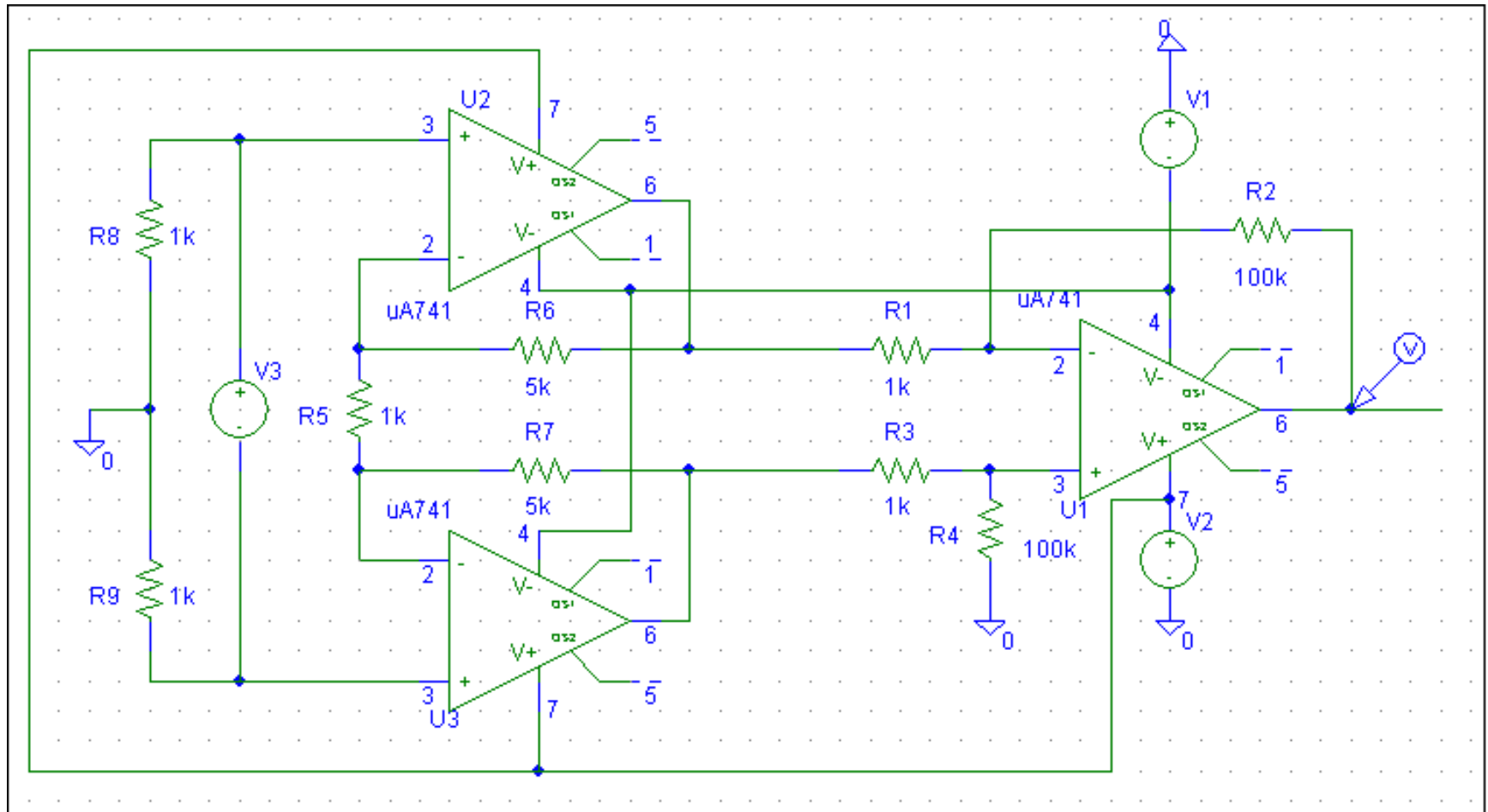
## SIM 2.7: $v_O(t)$



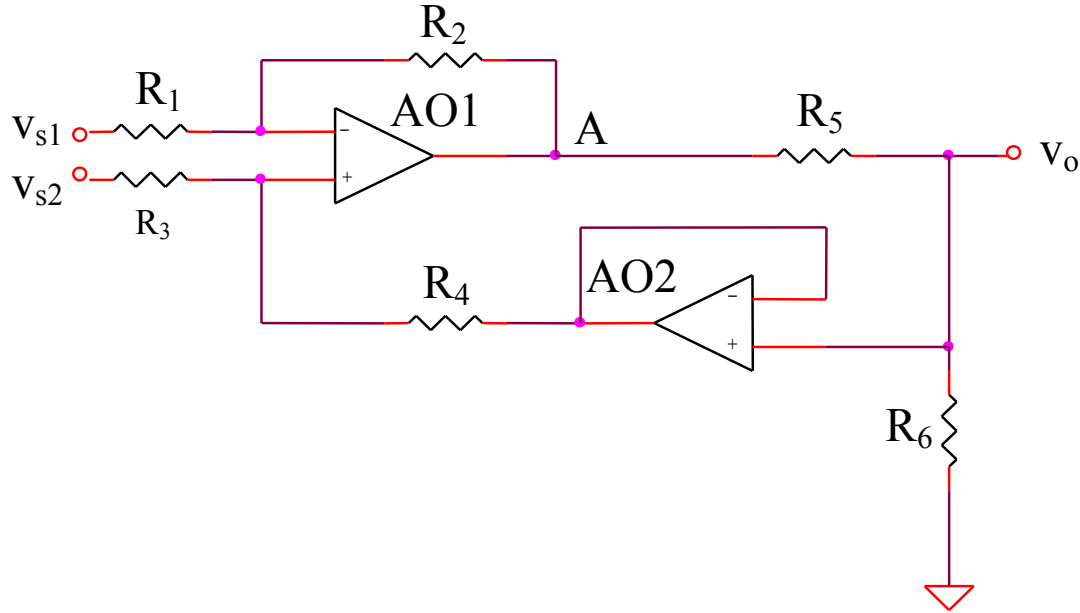


## SIMULARI pentru circuitul de diferenta (2)

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



## 2.2.12. Circuitul de diferenta (3)



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

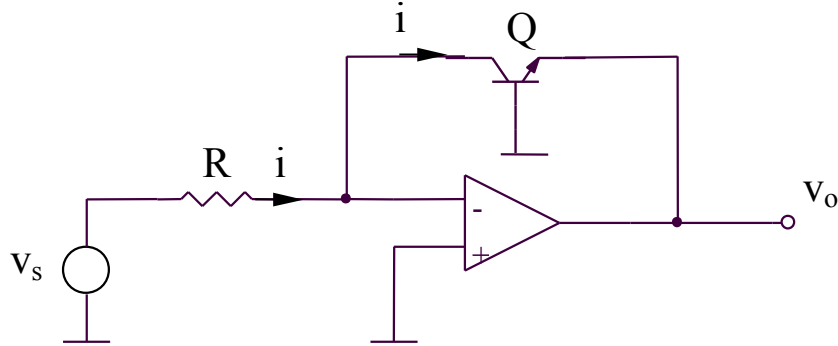
$$v_o = v_A \frac{R_6}{R_5 + R_6}$$

$$\Rightarrow v_o \left[ \left( 1 + \frac{R_5}{R_6} \right) - \frac{1 + \frac{R_2}{R_1}}{1 + \frac{R_4}{R_3}} \right] = v_{s2} \frac{1 + \frac{R_2}{R_1}}{1 + \frac{R_3}{R_4}} - v_{s1} \frac{R_2}{R_1}$$

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

$$\Rightarrow R_1 R_4 = R_2 R_3 \Rightarrow A = \frac{v_o}{v_{s2} - v_{s1}} = \frac{R_6 R_2}{R_5 R_1}$$

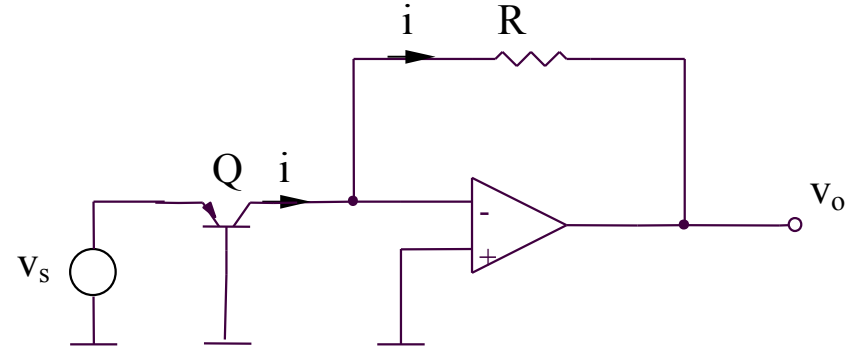
## 2.2.13. Convertoarele logaritmice si anti-logaritmice



**Convertorul logaritmice**

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

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



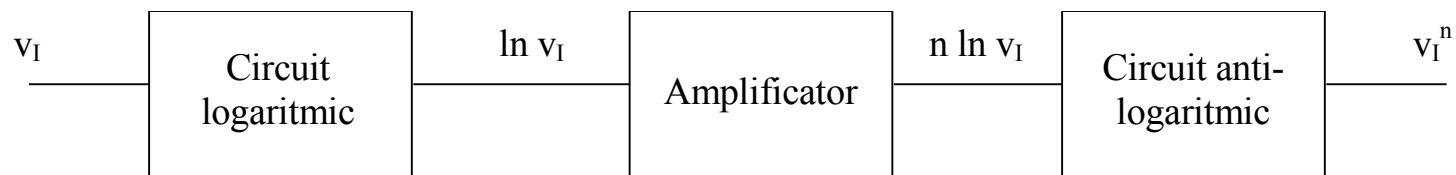
**Convertorul anti-logaritmice**

$$v_o = -iR$$

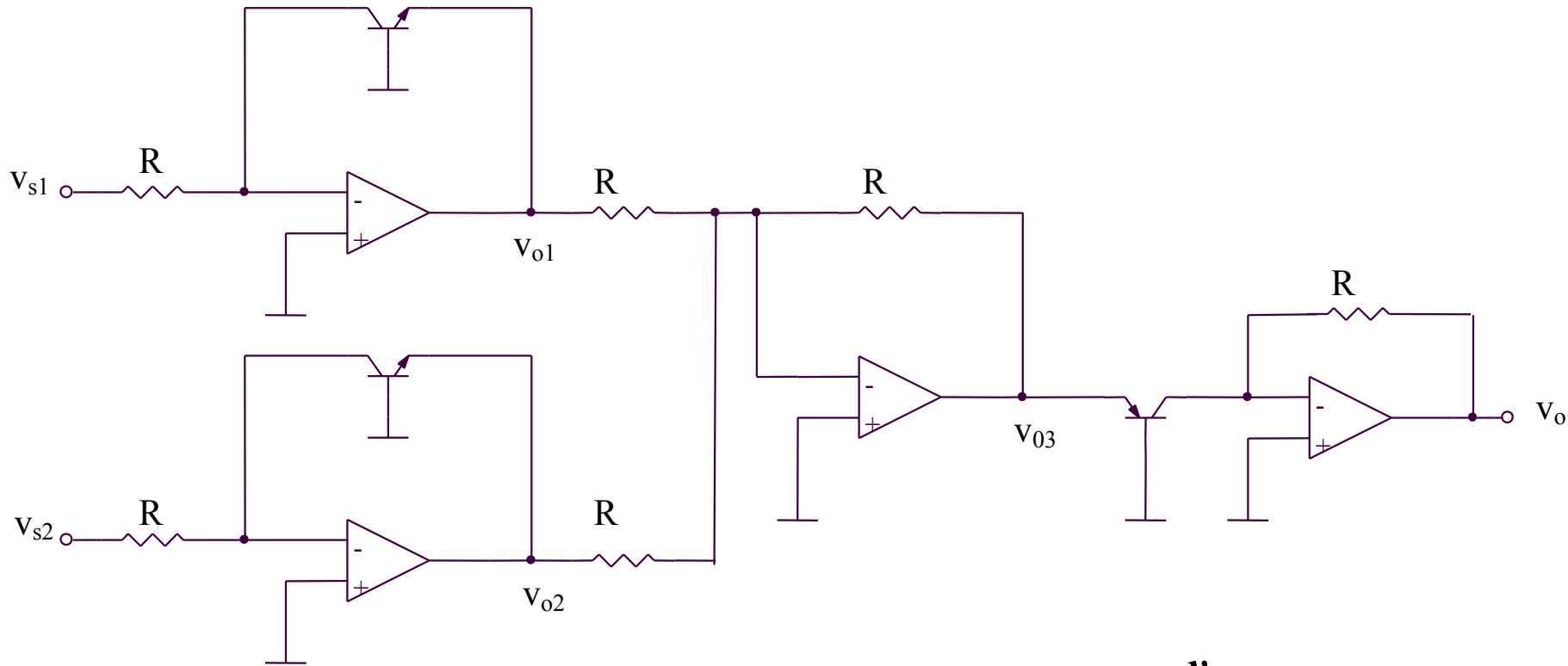
$$i = I_S e^{\frac{v_{EB}}{V_{th}}} = I_S e^{\frac{v_s}{V_{th}}}$$

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

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



## 2.2.15. Circuit de multiplicare



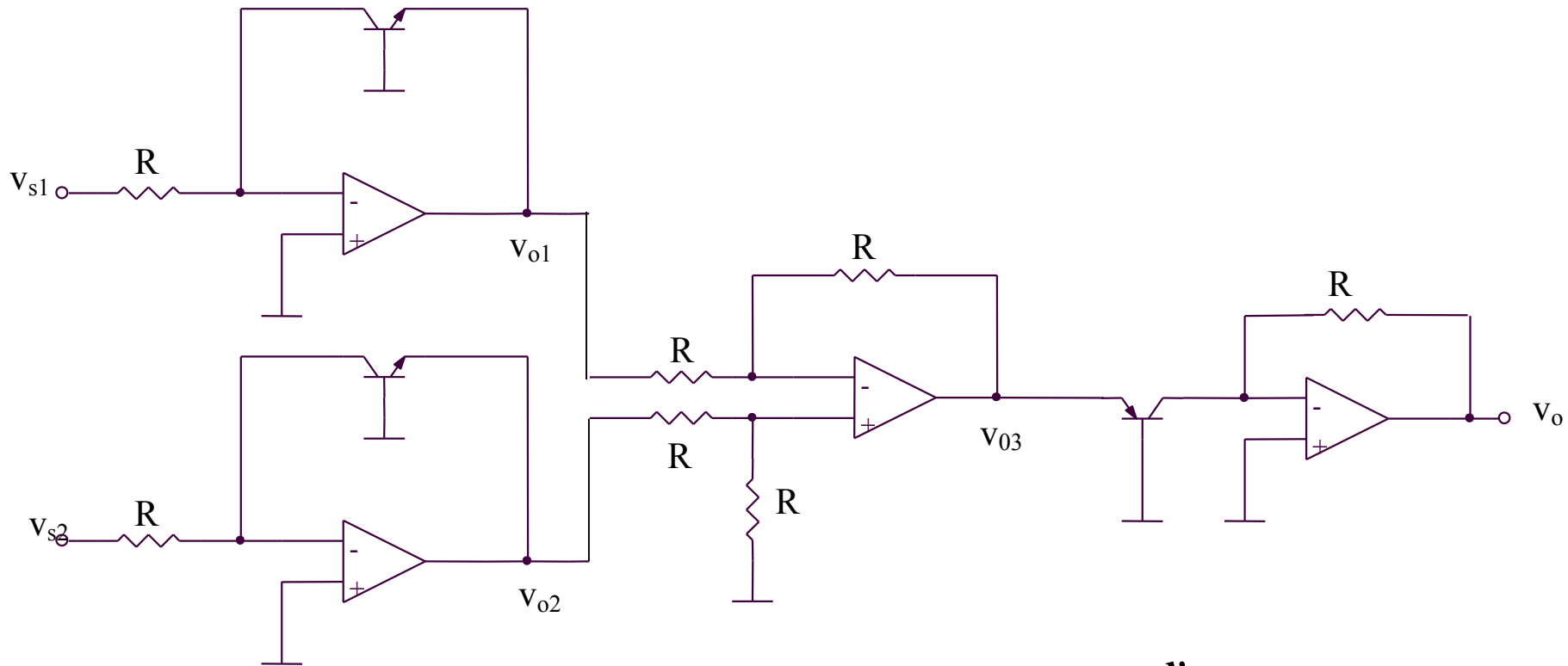
$$v_{o1} = -V_{th} \ln \frac{v_{s1}}{RI_S}$$

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

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

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

## 2.2.16. Circuit de impartire



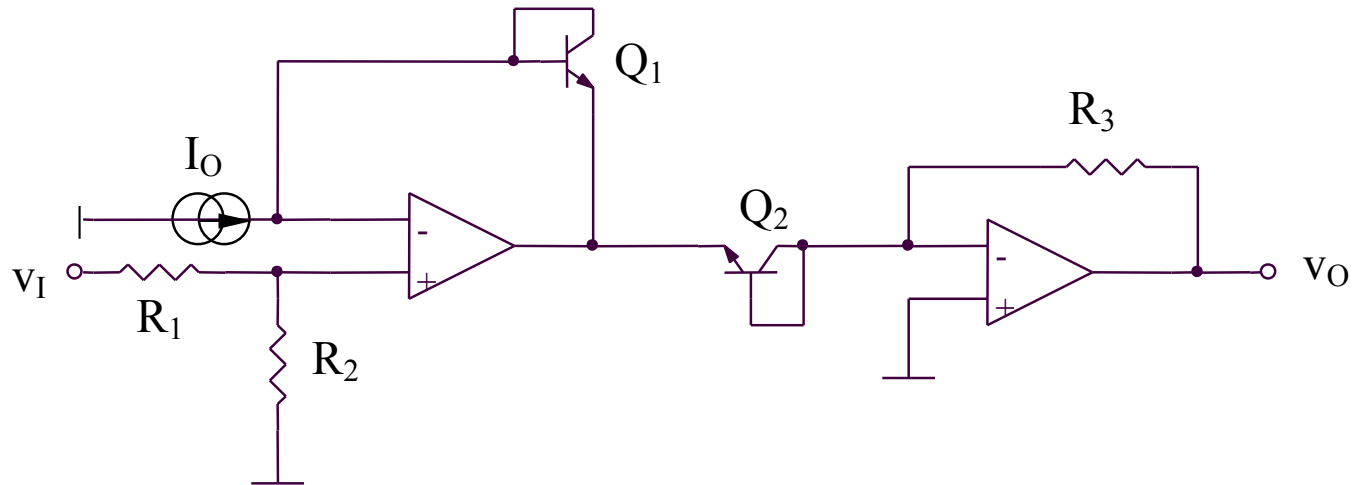
$$v_{o1} = -V_{th} \ln \frac{v_{s1}}{RI_S}$$

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

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

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

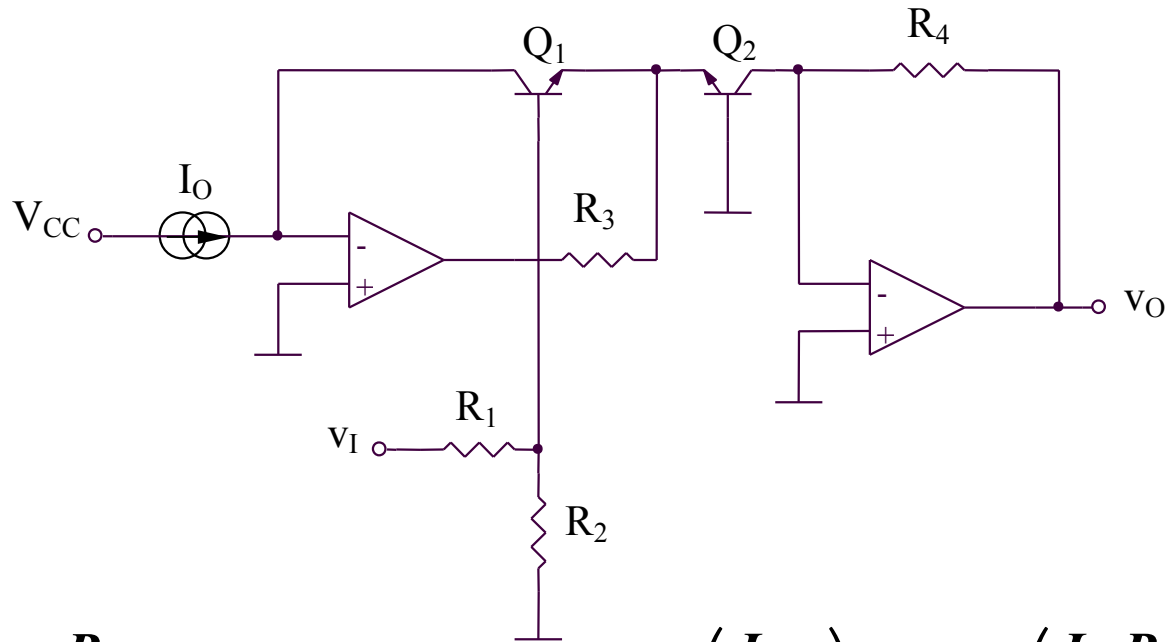
## 2.2.17. Circuit de exponentielle (1)



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

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

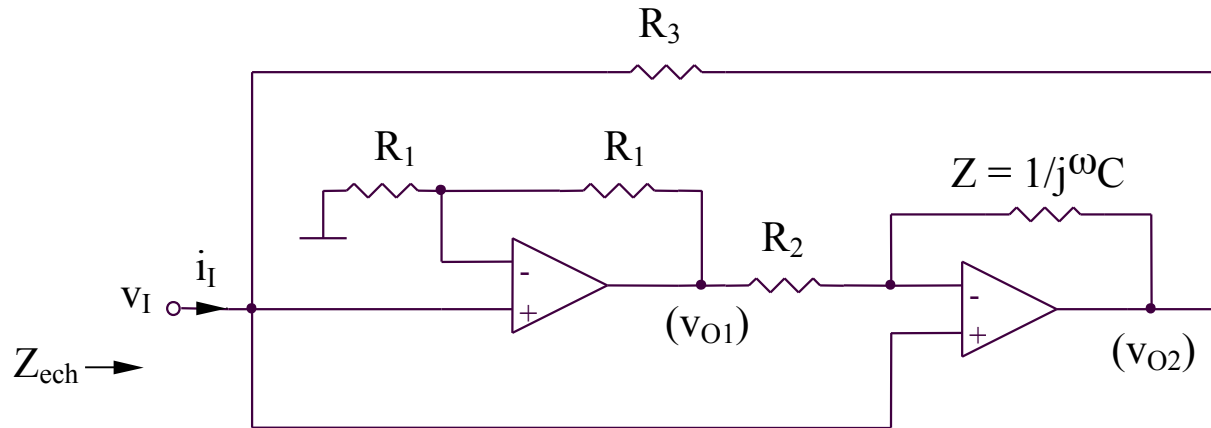
## 2.2.18. Circuit de exponentiere (2)



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

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

## 2.2.19. Simulator de impedanta



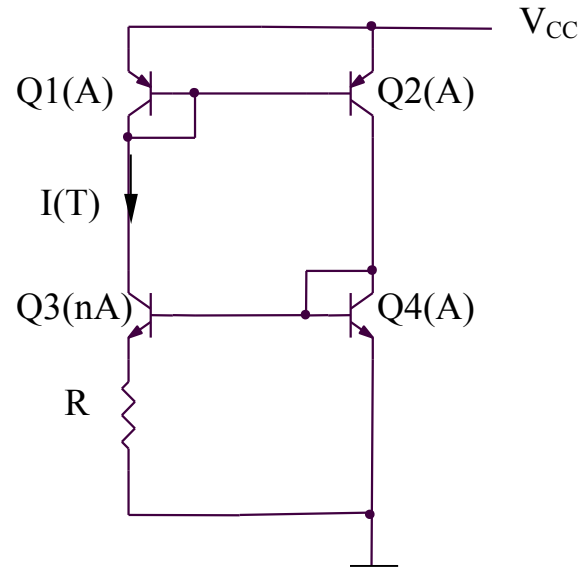
$$\left. \begin{aligned} v_{O2} &= v_I \left( 1 + \frac{Z}{R_2} \right) + v_{O1} \left( -\frac{Z}{R_2} \right) \\ v_{O1} &= 2v_I \end{aligned} \right\} \Rightarrow \left. \begin{aligned} v_{O2} &= v_I \left( 1 - \frac{Z}{R_2} \right) \\ i_I &= \frac{v_I - v_{O2}}{R_3} \end{aligned} \right\} \Rightarrow i_I = v_I \frac{Z}{R_2 R_3} \Rightarrow$$

$$\Rightarrow Z_{ech} = \frac{v_I}{i_I} = \frac{R_2 R_3}{Z} = j\omega(R_2 R_3 C) = j\omega L_{ech}$$

$$L_{ech} = R_2 R_3 C$$

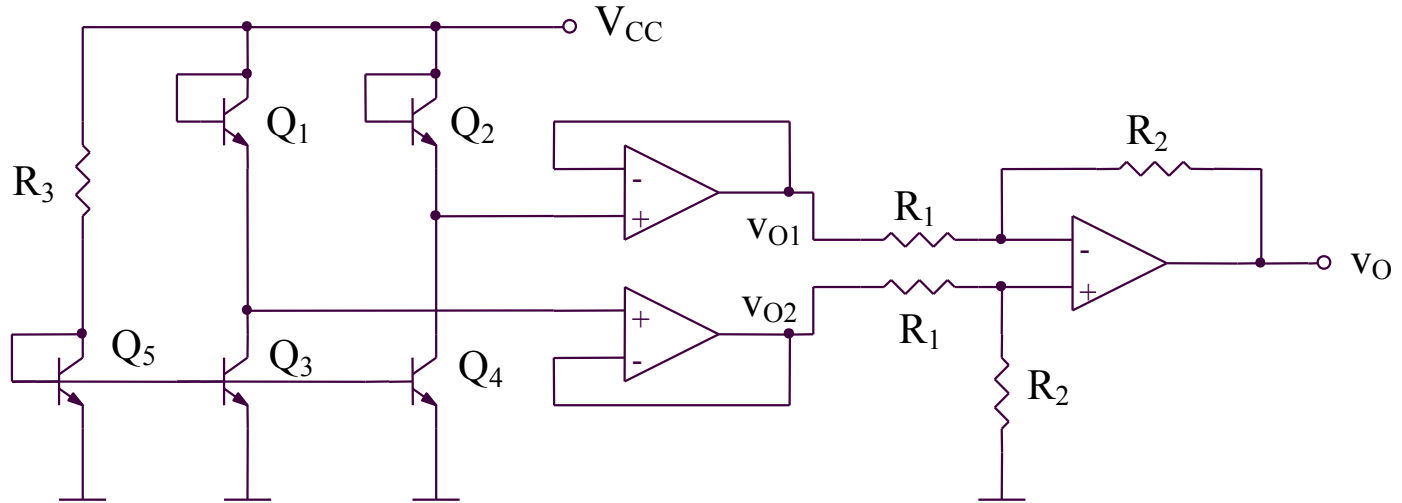


## 2.2.20. Sensori de temperatura (1)



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

## 2.2.21. Sensori de temperatura (2)

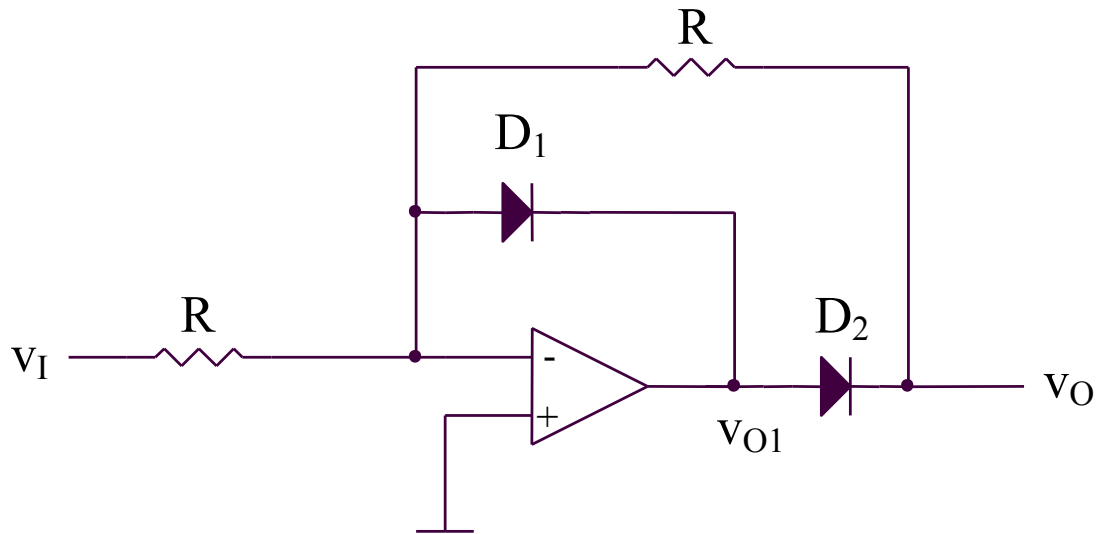


$$v_O = \frac{R_2}{R_1} (v_{O2} - v_{O1}) = \frac{R_2}{R_1} (v_{BE2} - v_{BE1}) = \frac{R_2}{R_1} V_{th} \ln \left( \frac{I_{C2} I_{S1}}{I_{C1} I_{S2}} \right) \Rightarrow$$

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

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

## 2.2.22. Redresor mono-alternanta

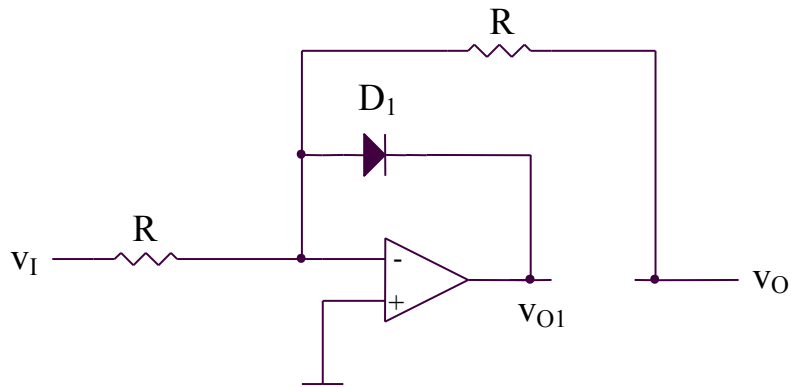


$v_I > 0 \Rightarrow v_{O1} < 0 \Rightarrow D_1$  deschisa,  $D_2$  blocata

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

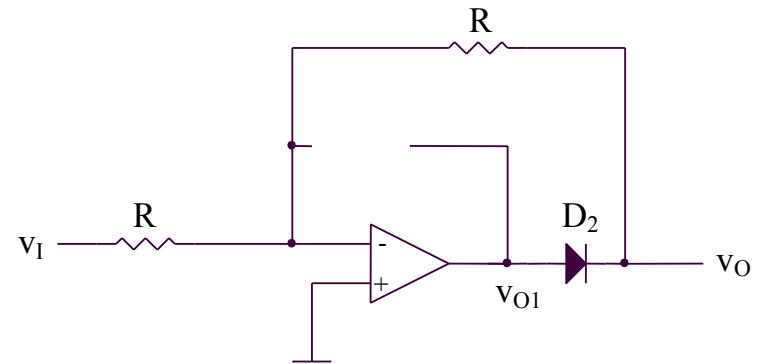
## 2.2.22. Redresor mono-alternanta

$$v_I > 0$$



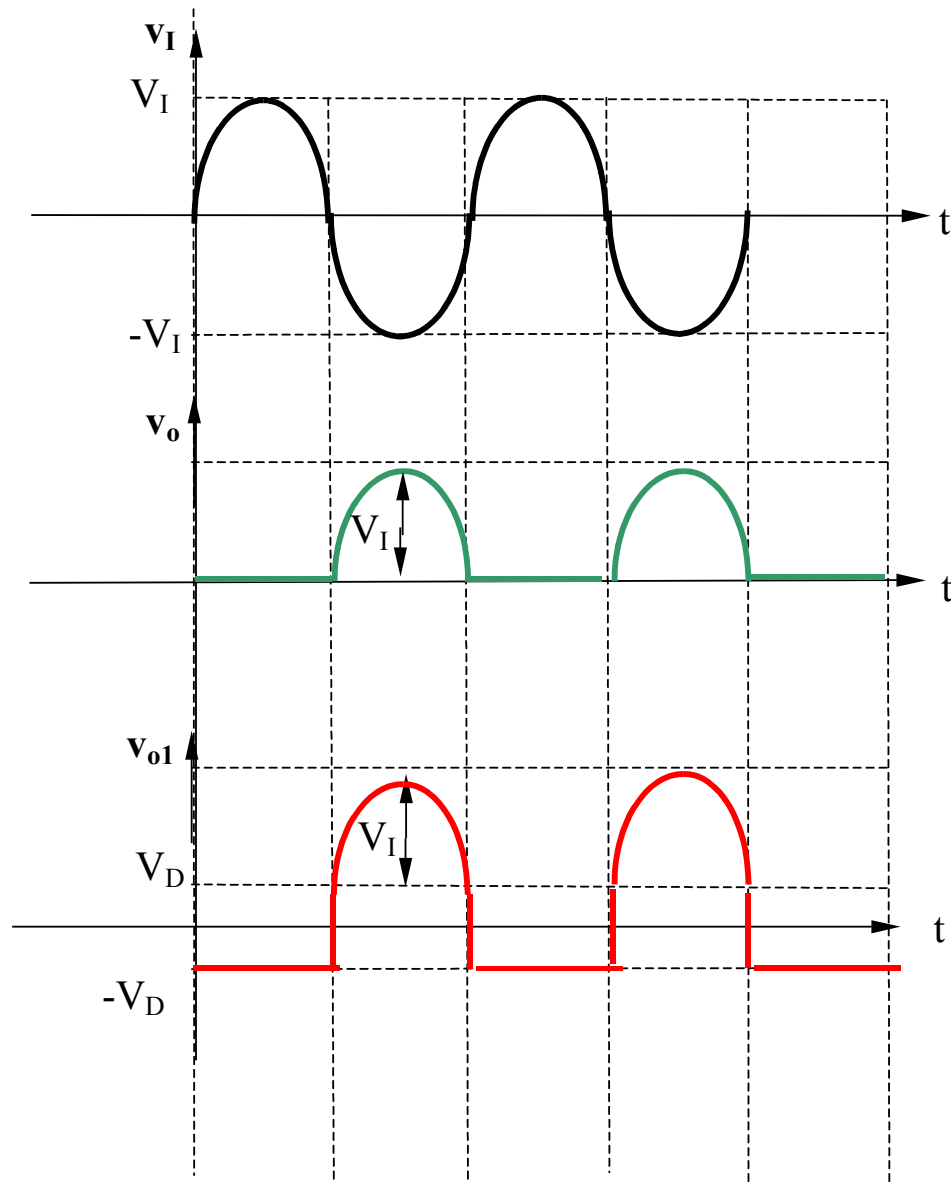
$$v_O = 0$$

$$v_I < 0$$



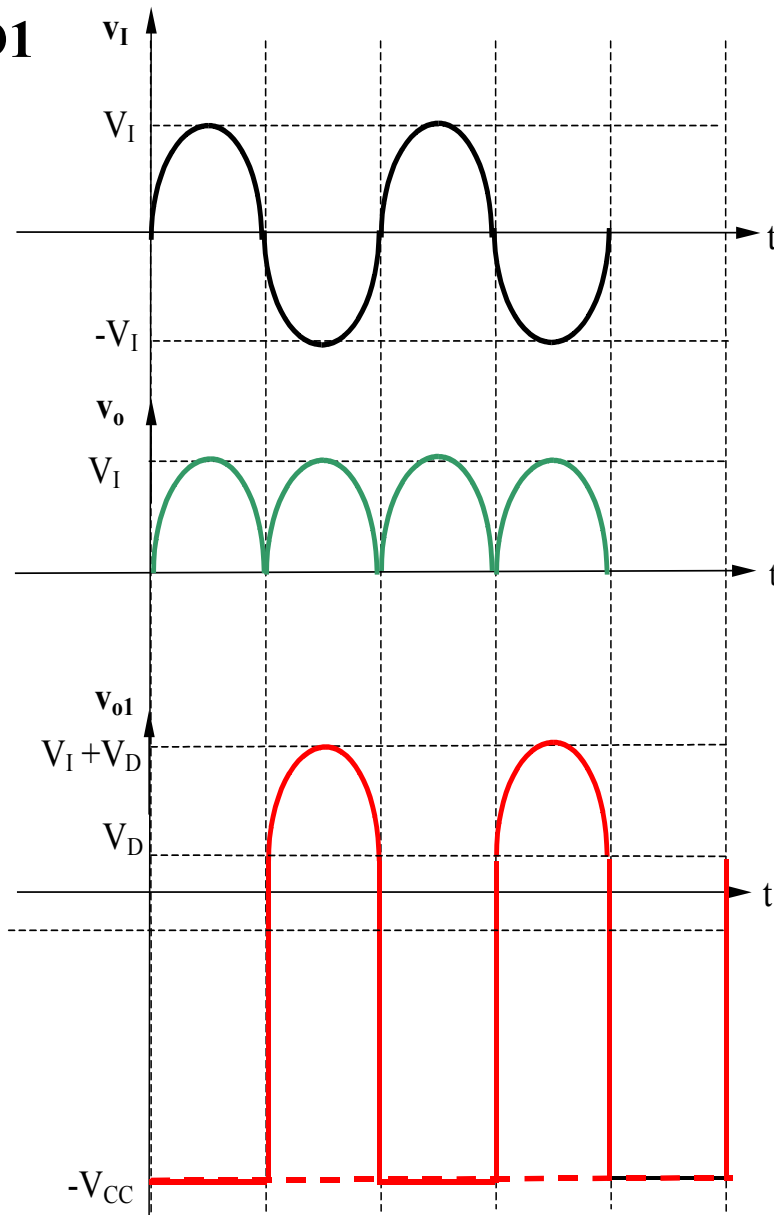
$$v_O = -\frac{R}{R}v_I = -v_I$$

## 2.2.22. Redresor mono-alternanta



## 2.2.22. Redresor mono-alternanta

Fara D1



Exemplu

$$f=10\text{kHz}$$

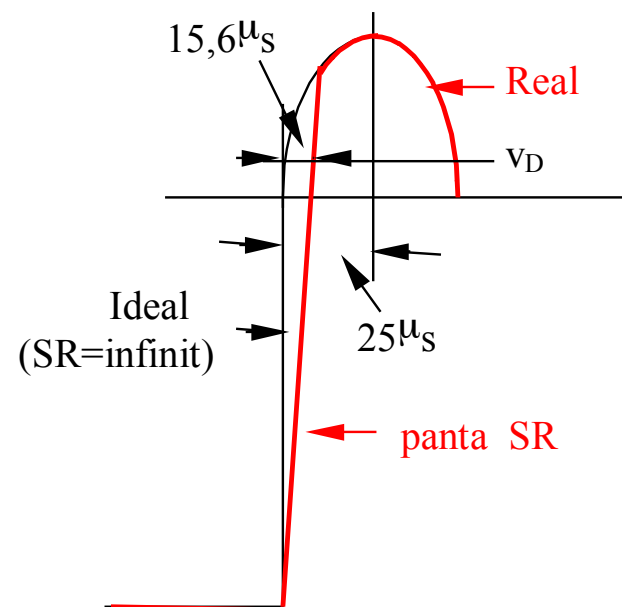
$$T=1/f=100\ \mu\text{s}$$

$$T/2=50\ \mu\text{s}$$

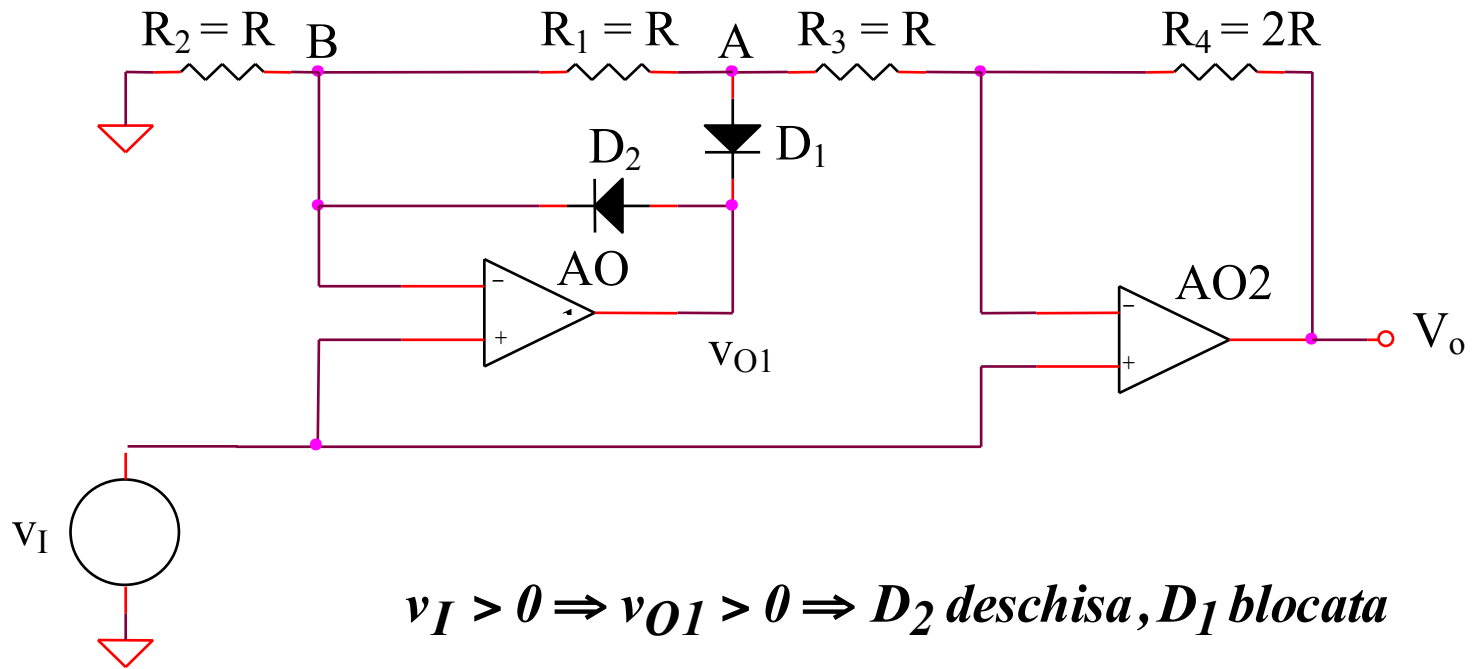
$$SR=1\text{V}/\mu\text{s}$$

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

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



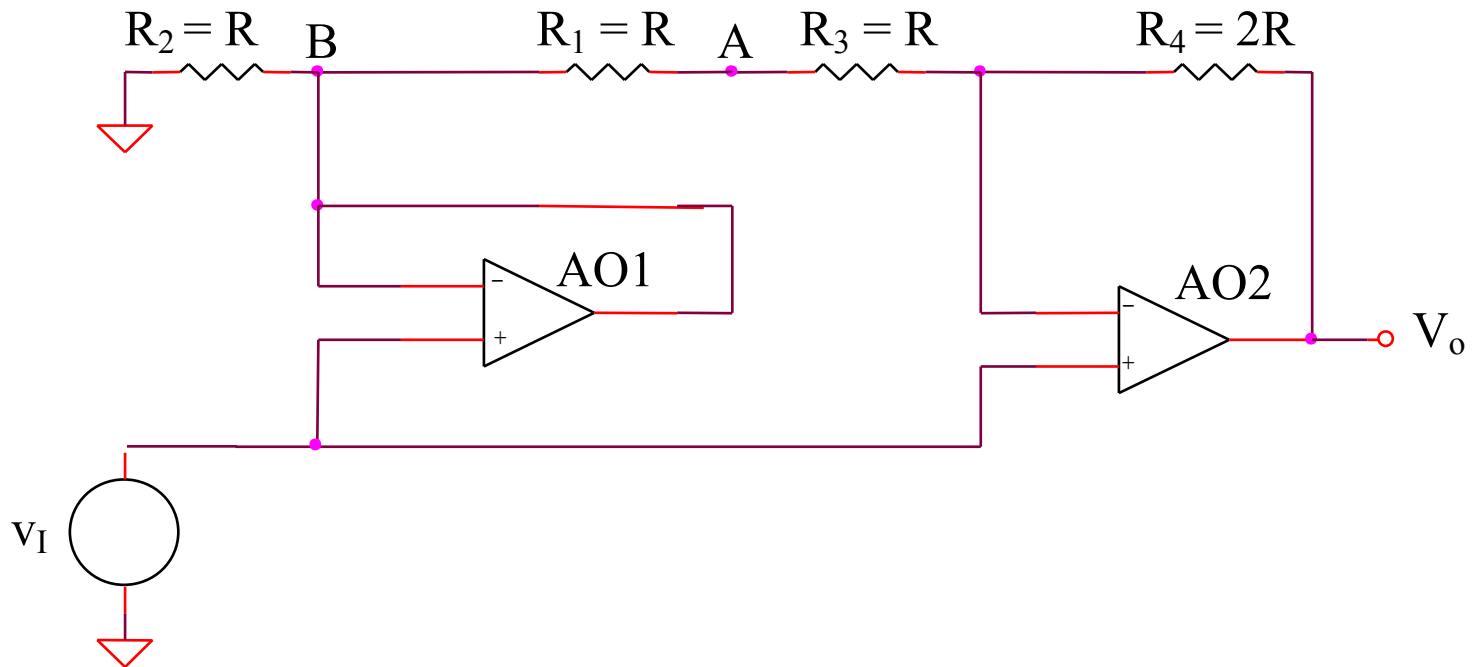
## 2.2.23. Redresor bi-alternanta (1)



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

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

## 2.2.23. Redresor bi-alternanta (1)



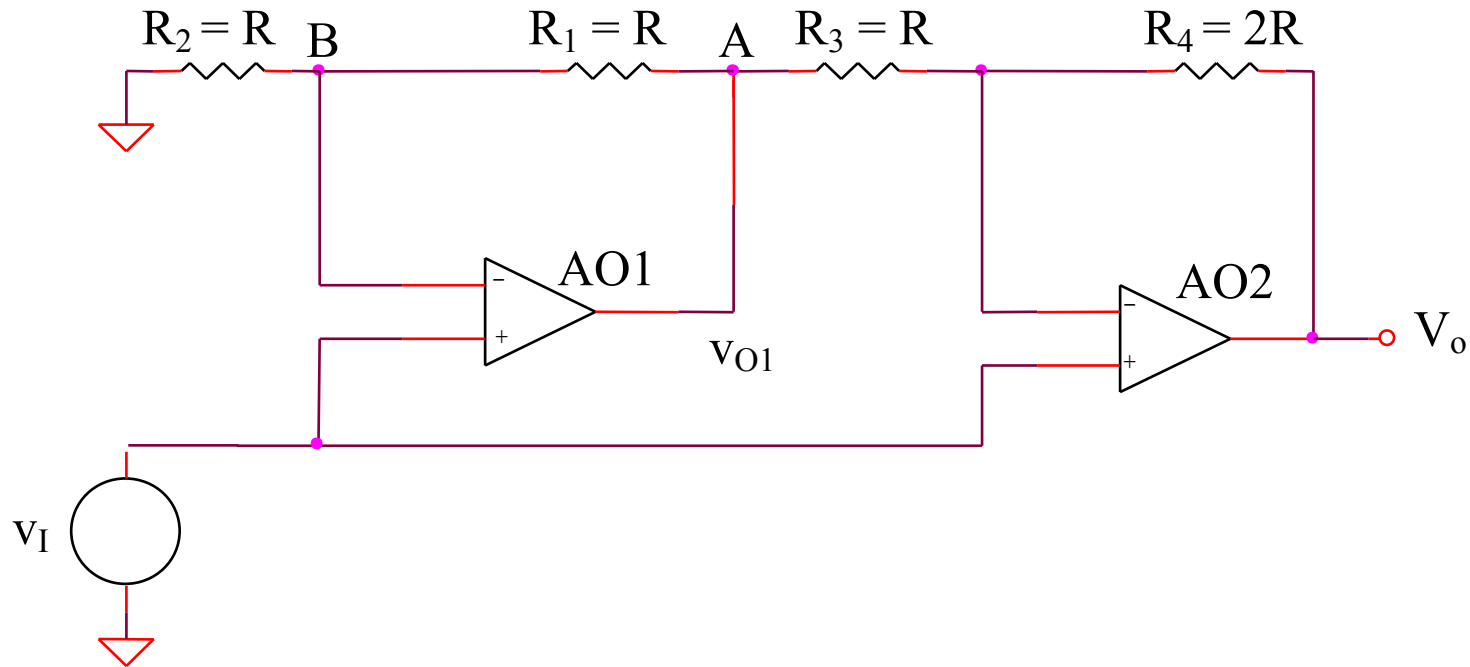
$$v_I > 0$$

$$V_B = v_I$$

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



## 2.2.23. Redresor bi-alternanta (1)



$$v_I < 0$$

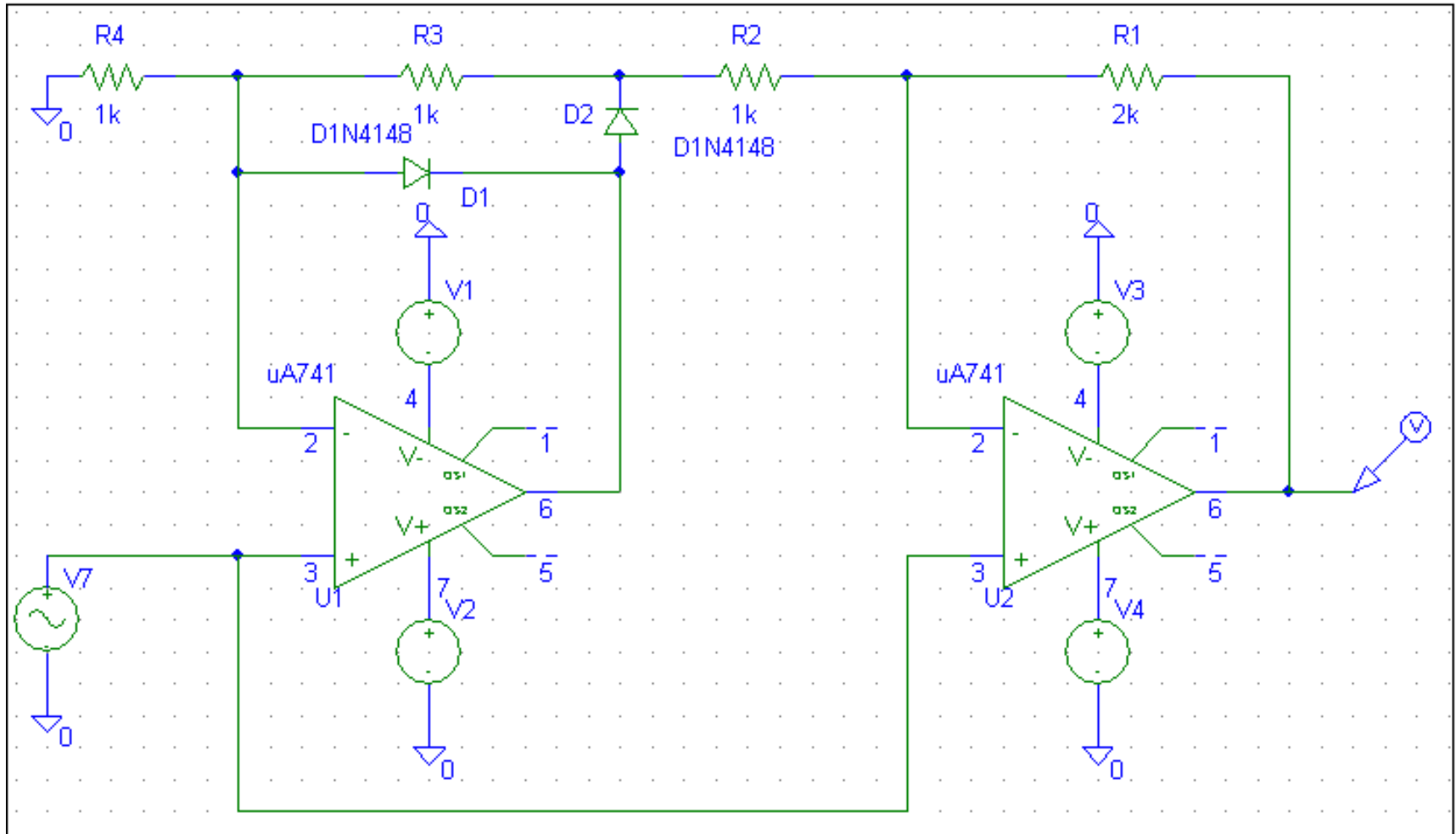
$$V_A = \left(1 + \frac{R_1}{R_2}\right)v_I = 2v_I \quad v_O = \left(1 + \frac{R_4}{R_3}\right)v_I - \frac{R_4}{R_3}V_A = -v_I$$

Concluzie:  $v_O = |v_I|$

# **SIMULARI pentru redresorul bialternanta (1)**

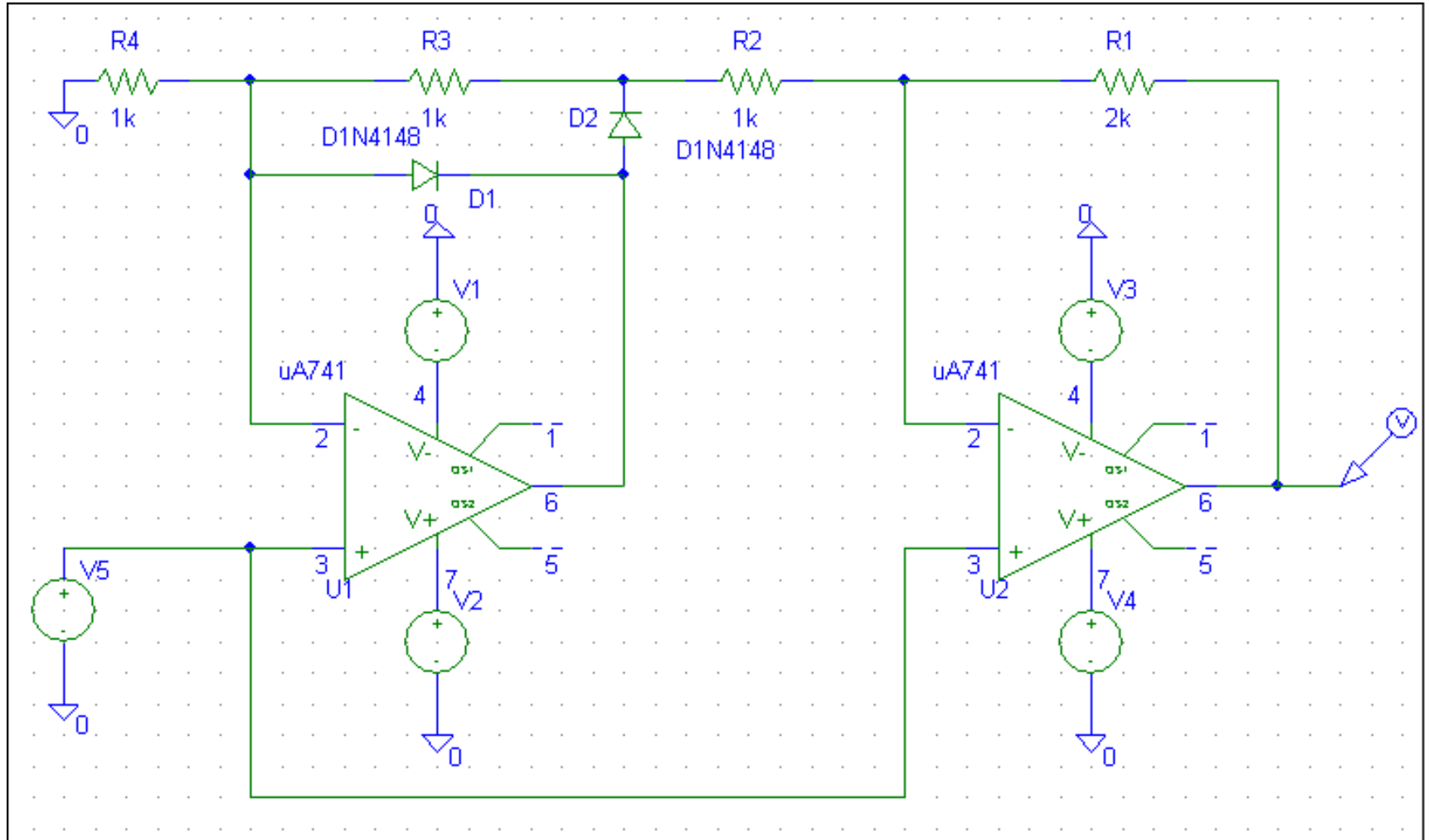
# SIMULARI pentru redresorul bialternanta (2)

## SIM 2.9: $v_O(t)$

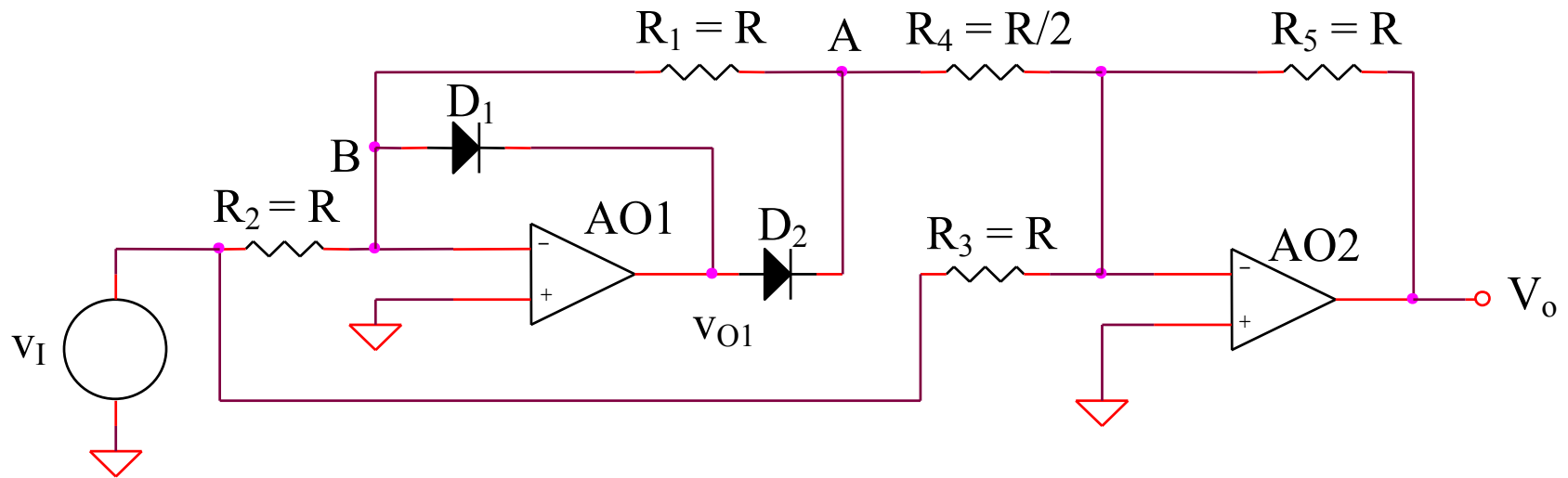


# SIMULARI pentru redresorul bialternanta (1)

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



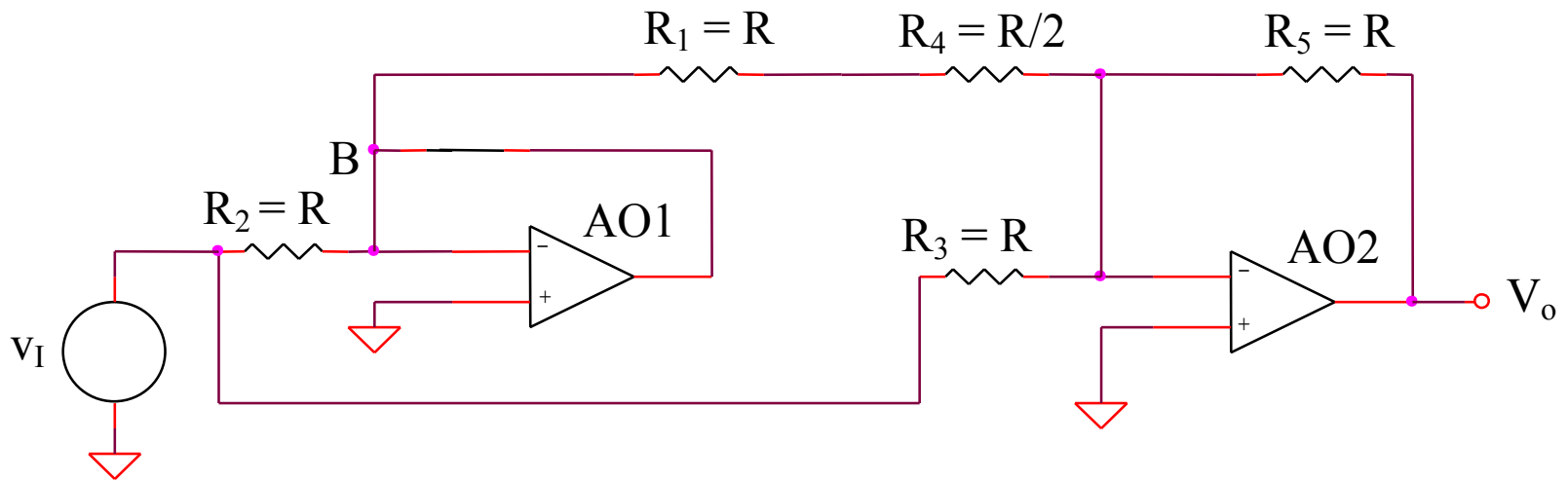
## 2.2.24. Redresor bi-alternanta (2)



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

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

## 2.2.24. Redresor bi-alternanta (2)

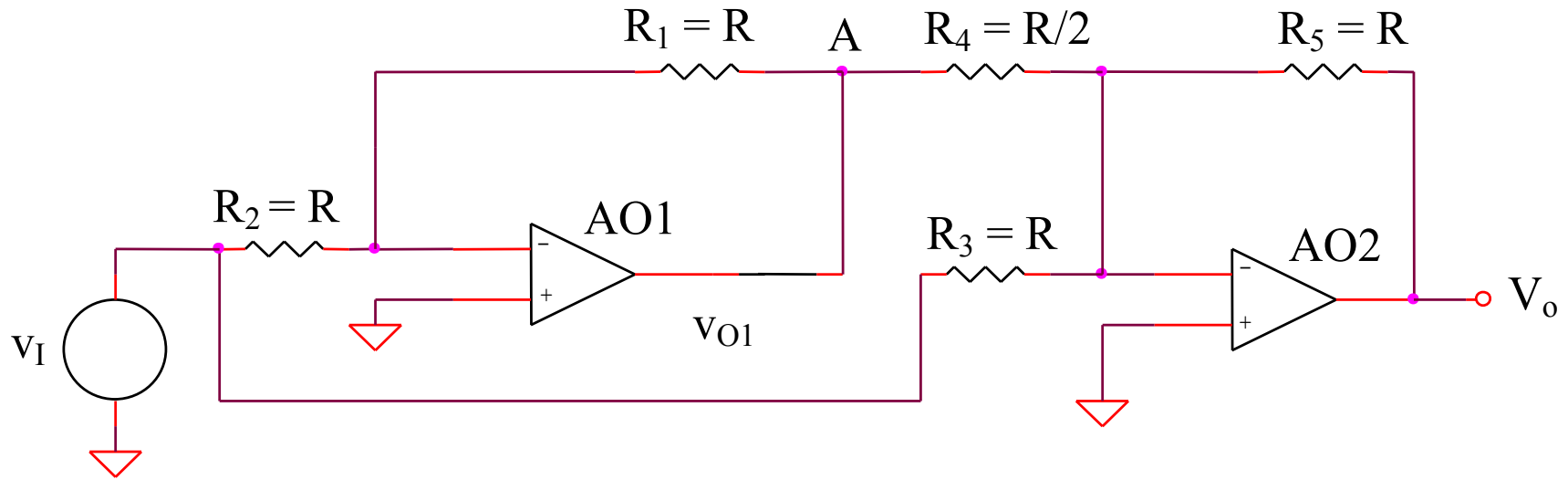


$$v_I > 0$$

$$V_B = 0$$

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

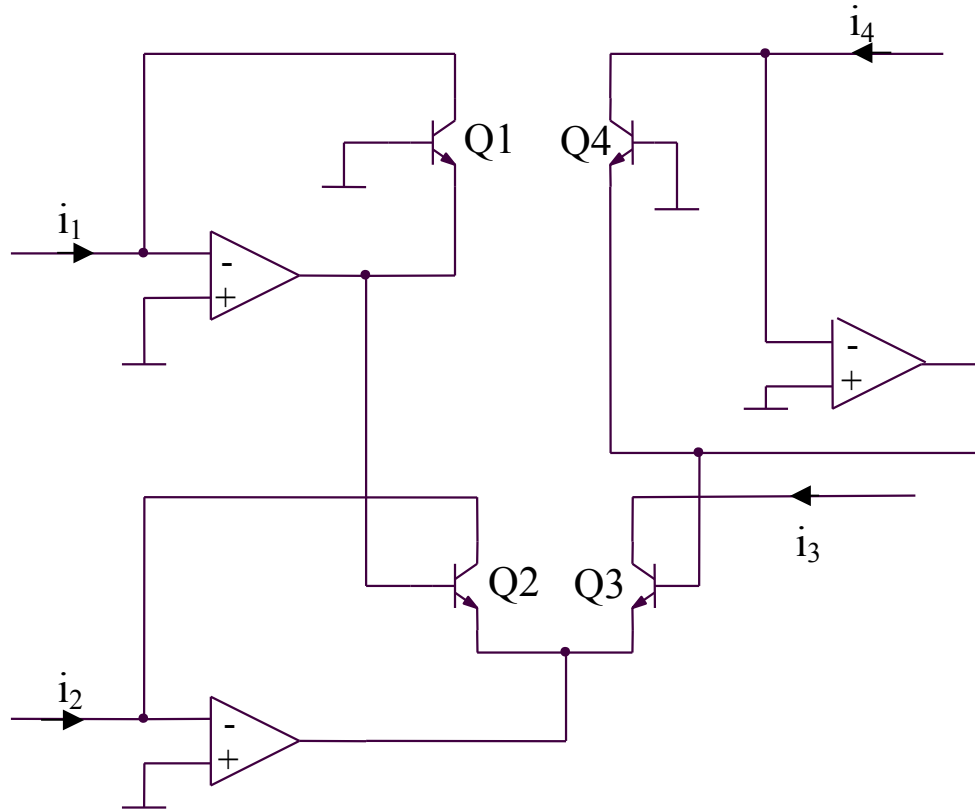
## 2.2.24. Redresor bi-alternanta (2)



$$v_I < 0 \quad V_A = -\frac{R_1}{R_2} v_I \quad v_O = -\frac{R_5}{R_4} V_A - \frac{R_5}{R_3} v_I = v_I$$

Concluzie:  $v_O = -|v_I|$

## 2.2.25. Circuit multifunctional RC 4200

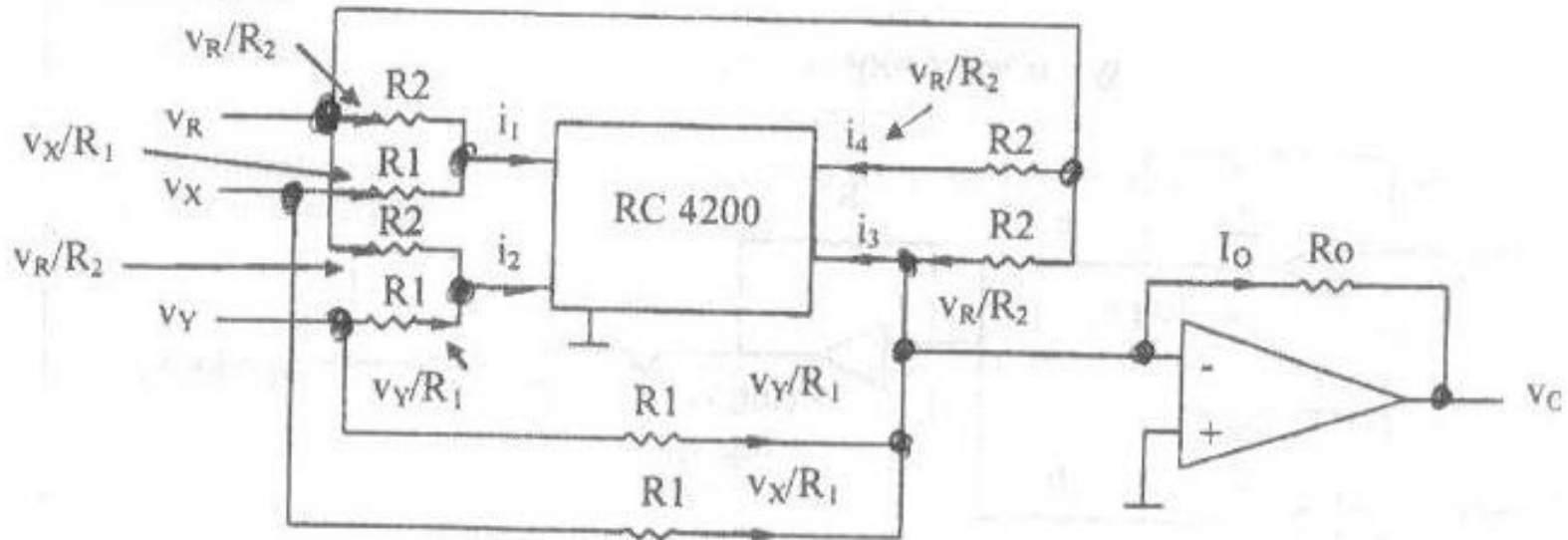


$$V_{BE1} + V_{BE2} = V_{BE3} + V_{BE4}$$

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



## 2.2.25. Circuit multifunctional RC 4200 - aplicatie

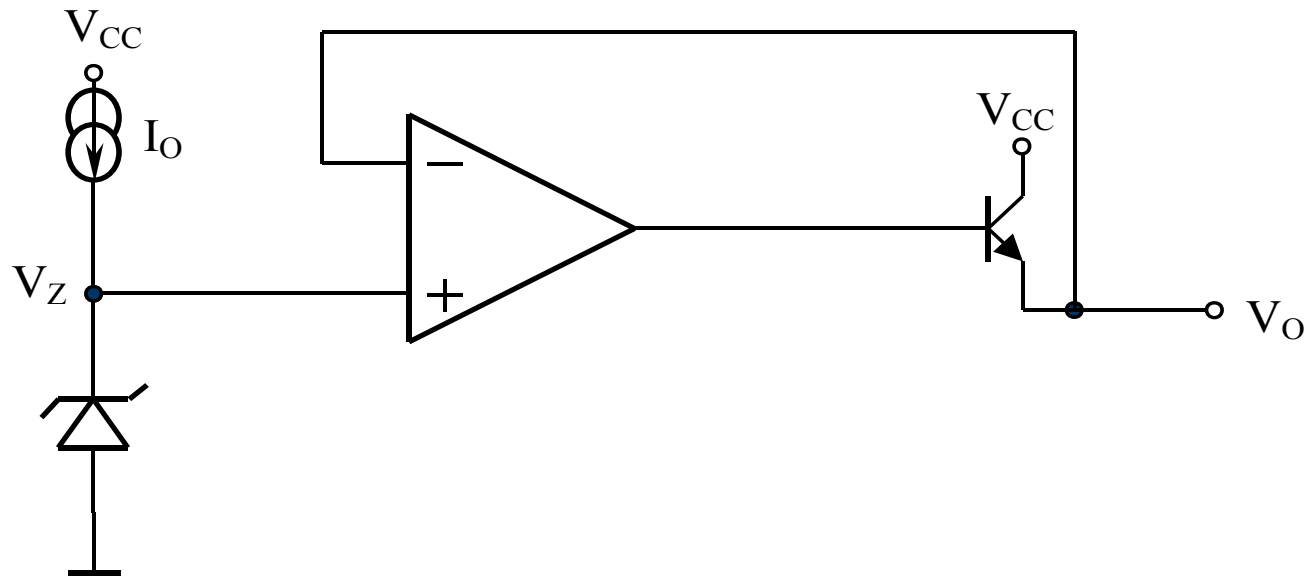


$$i_3 = \frac{i_1 i_2}{i_4} = \frac{R_2 \left( \frac{V_R}{R_2} + \frac{V_X}{R_1} \right) \left( \frac{V_R}{R_2} + \frac{V_Y}{R_1} \right)}{V_R \left( \frac{V_R}{R_2} + \frac{V_X}{R_1} \right)} = \frac{V_R}{R_2} + \frac{V_X}{R_1} + \frac{V_Y}{R_1} + \frac{R_2 V_X V_Y}{V_R R_1^2}$$

$$i_0 = \frac{V_R}{R_2} + \frac{V_X}{R_1} + \frac{V_Y}{R_1} - \left( \frac{V_R}{R_2} + \frac{V_X}{R_1} + \frac{V_Y}{R_1} + \frac{R_2 V_X V_Y}{V_R R_1^2} \right) = -\frac{R_2 V_X V_Y}{V_R R_1^2}$$

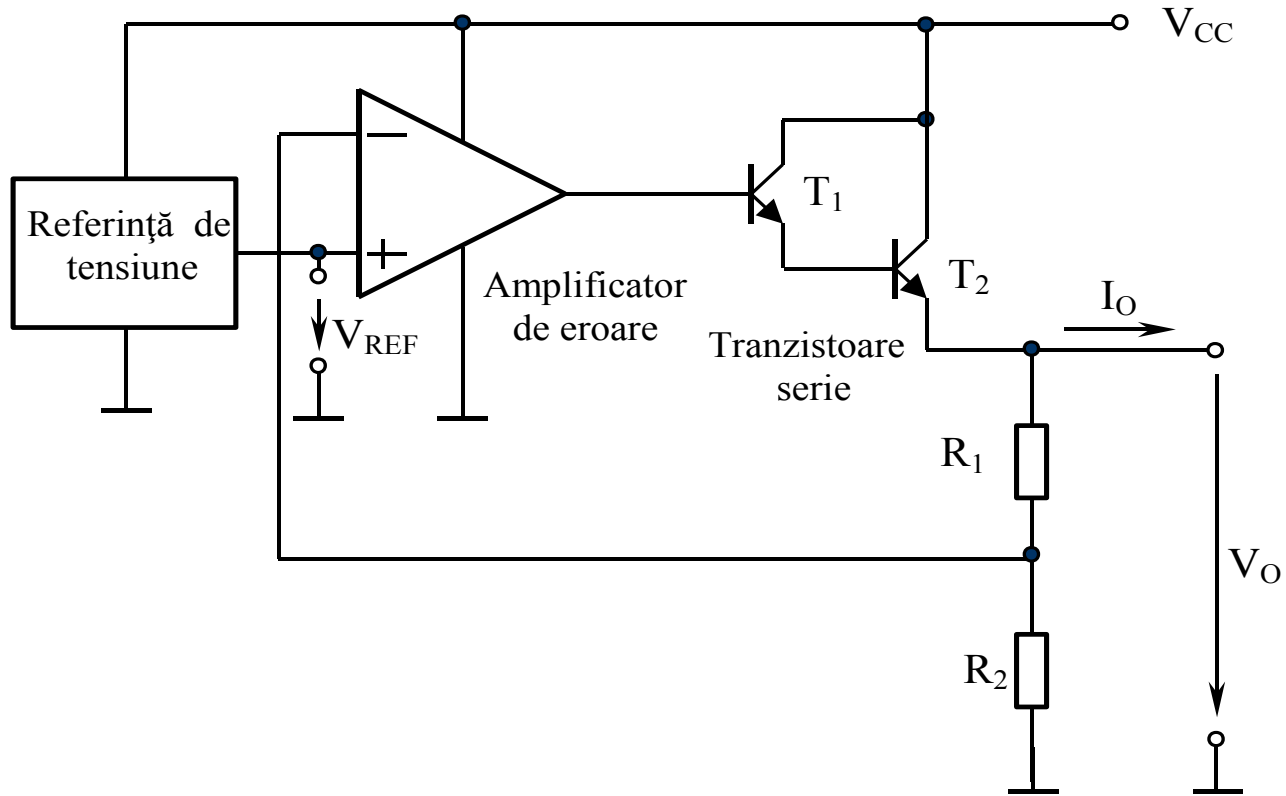
$$v_O = -i_0 R_O = \frac{R_2 R_O}{V_R R_1^2} V_X V_Y$$

## 2.2.26. Stabilizator de tensiune (1)



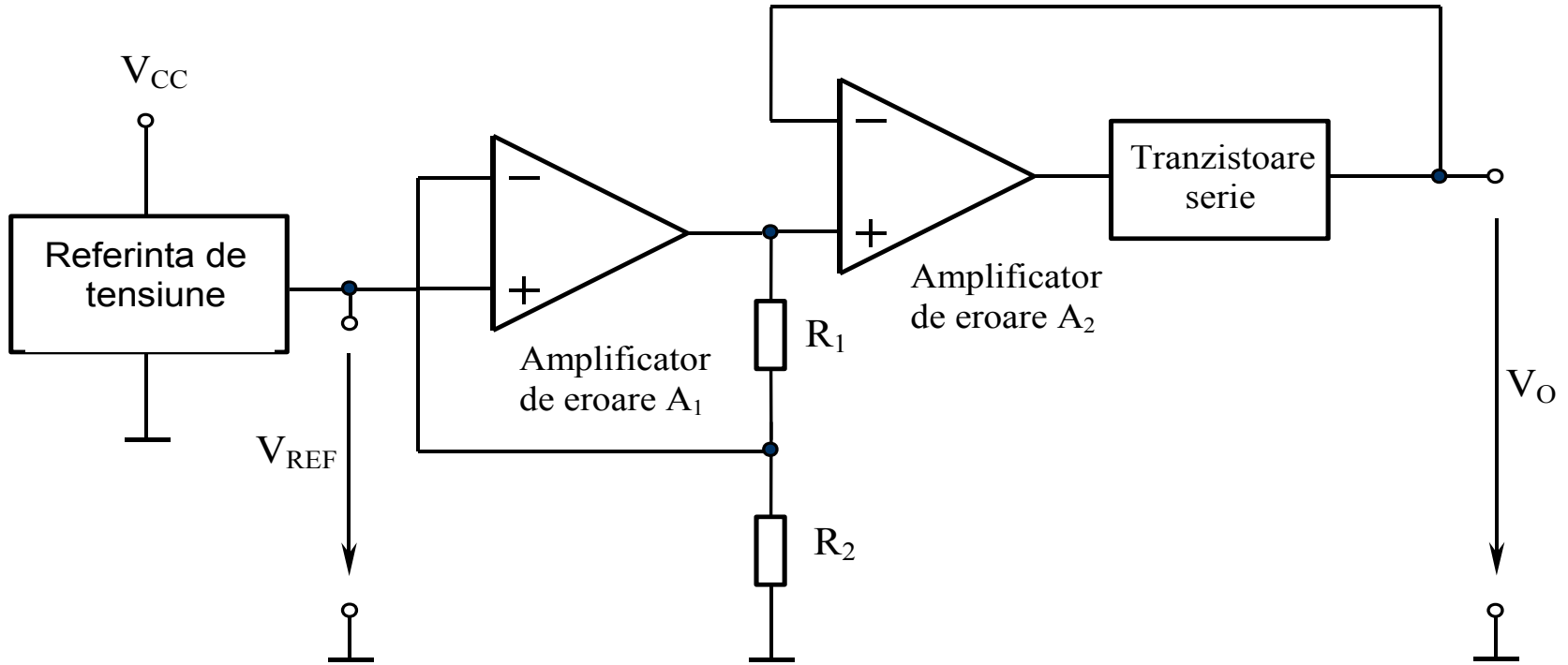
$$V_O = V_Z$$

## 2.2.27. Stabilizator de tensiune (2)



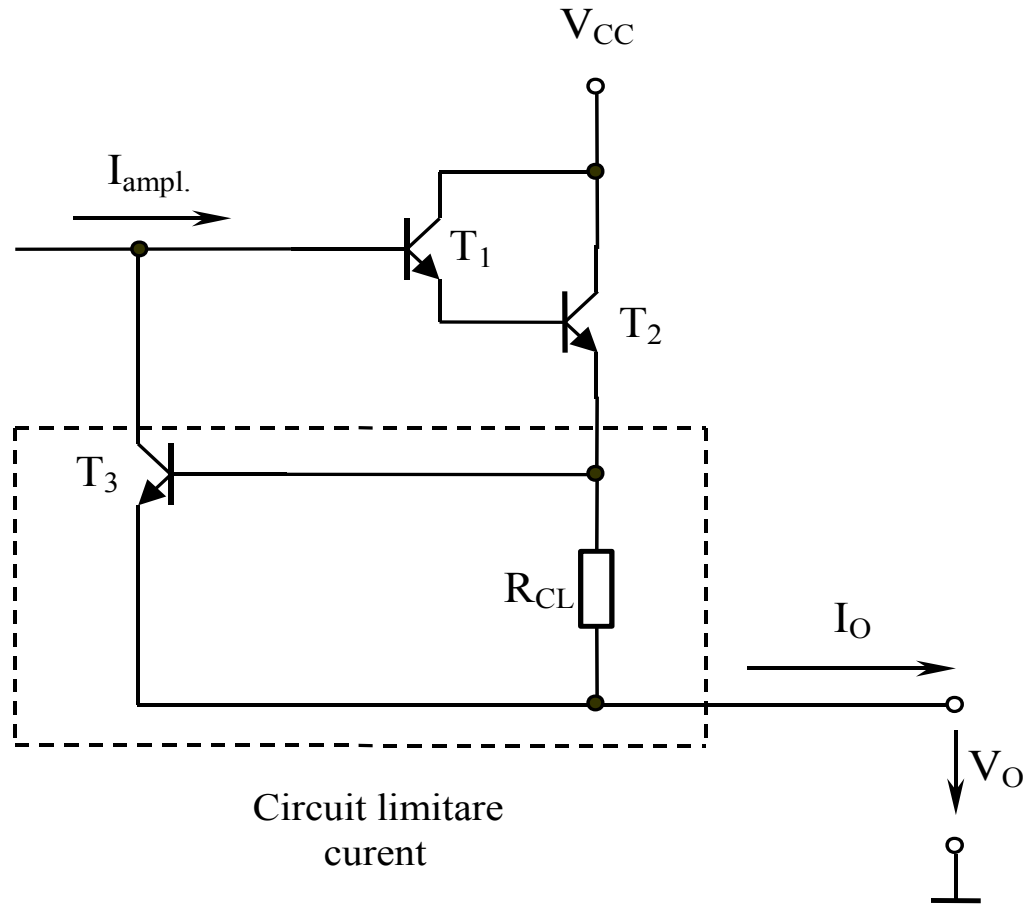
$$V_O \frac{R_2}{R_1 + R_2} = V_{REF} \Rightarrow V_O = V_{REF} \left( 1 + \frac{R_1}{R_2} \right)$$

## 2.2.28. Stabilizator de tensiune (3)



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

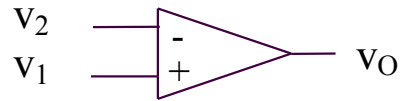
## 2.2.29. Circuit de protectie la supracurent



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

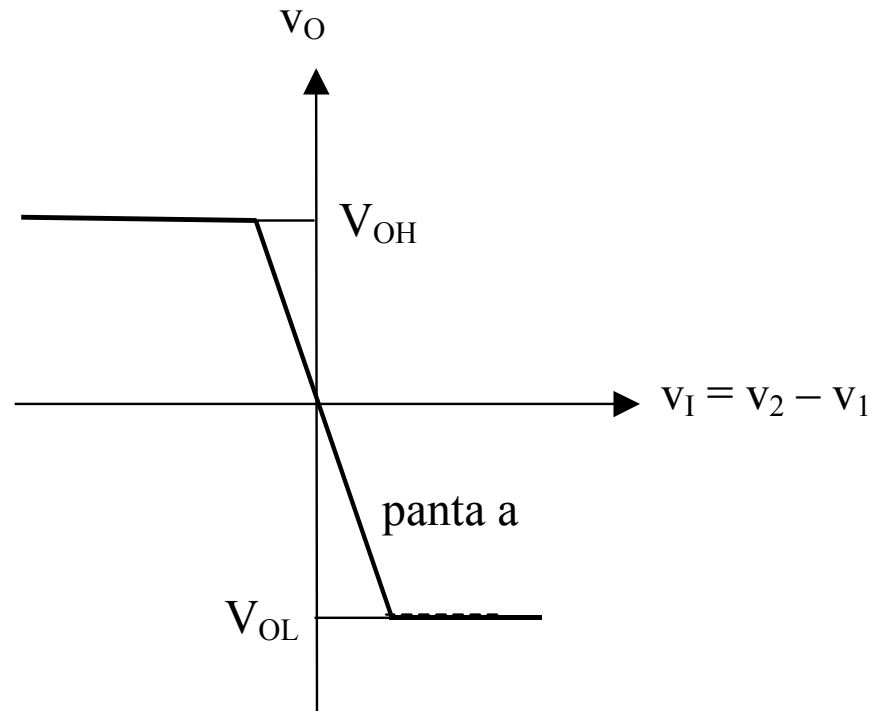
## **2.3. Comparatoare**

## 2.3.1. Comparator semplu

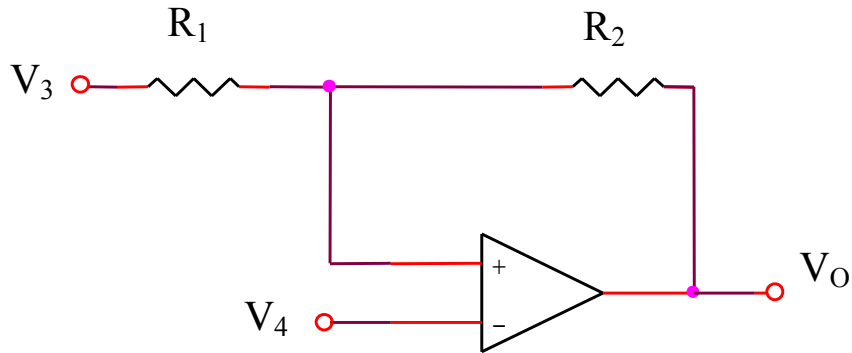


$$v_1 > v_2 \Rightarrow v_O = V_{OH}$$

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



## 2.3.2. Comparator cu histerezis

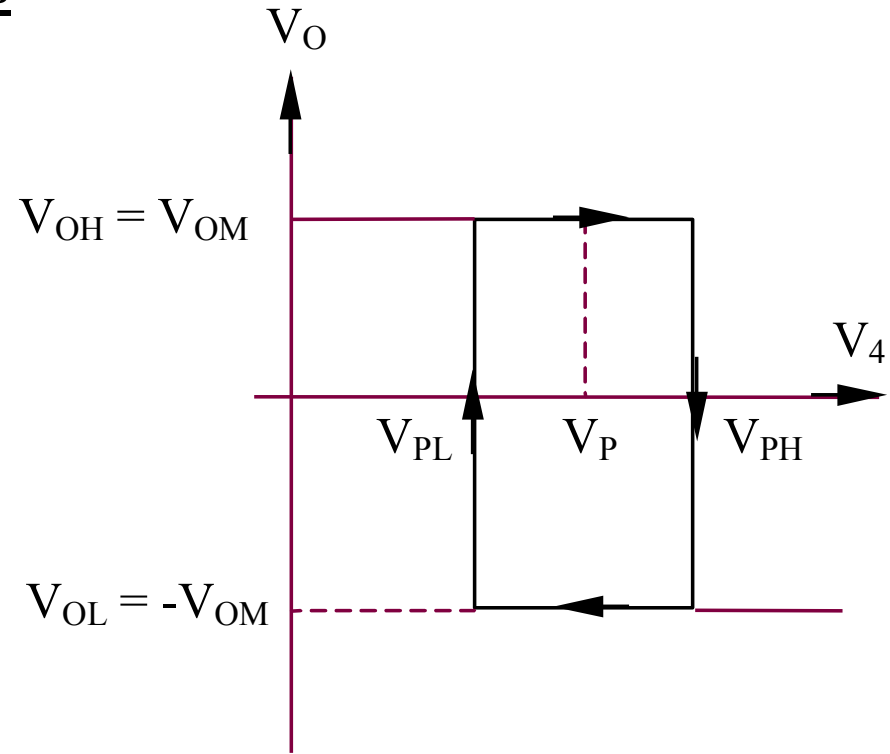


$V_3$  – sursa de tensiune constanta

$V_4$  – sursa de tensiune variabila

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

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



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

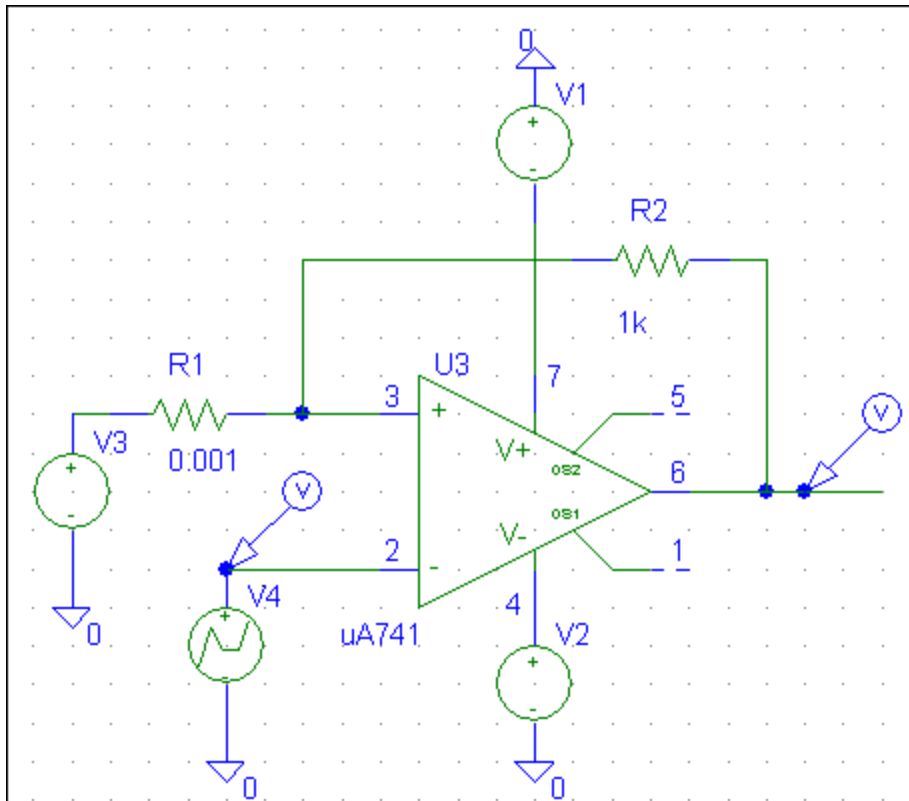
$$V_P = \frac{V_{PL} + V_{PH}}{2} = V_3 \frac{R_2}{R_1 + R_2}$$



## **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

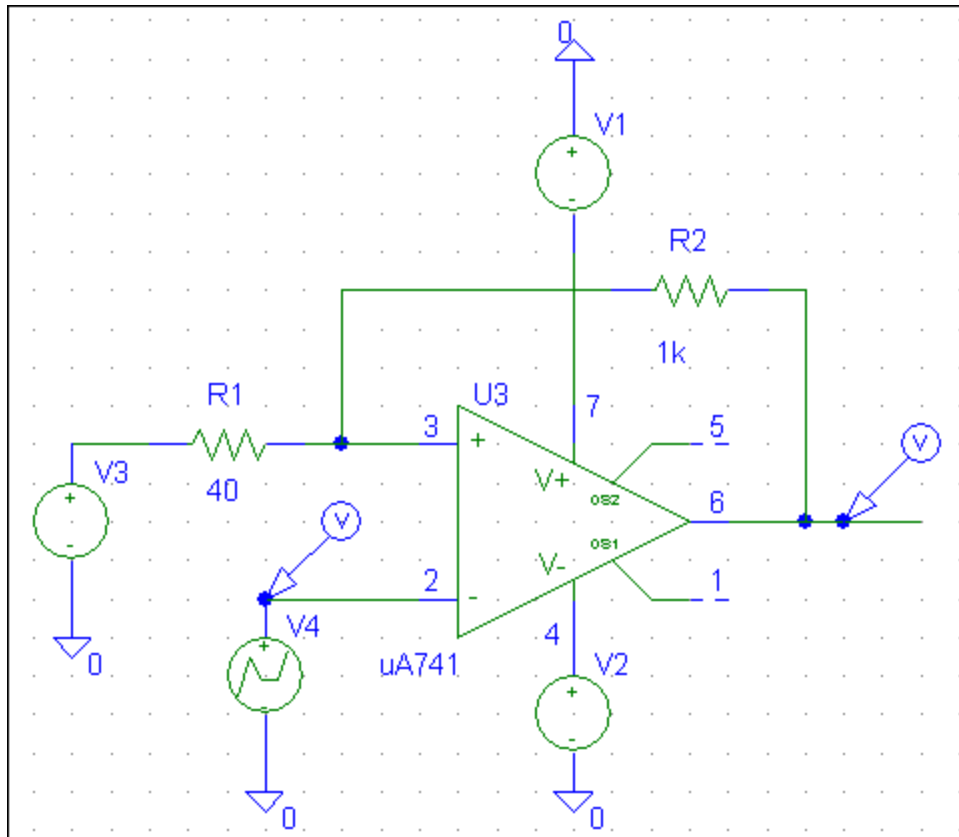
$$V_{OM} \cong 8,5V$$

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

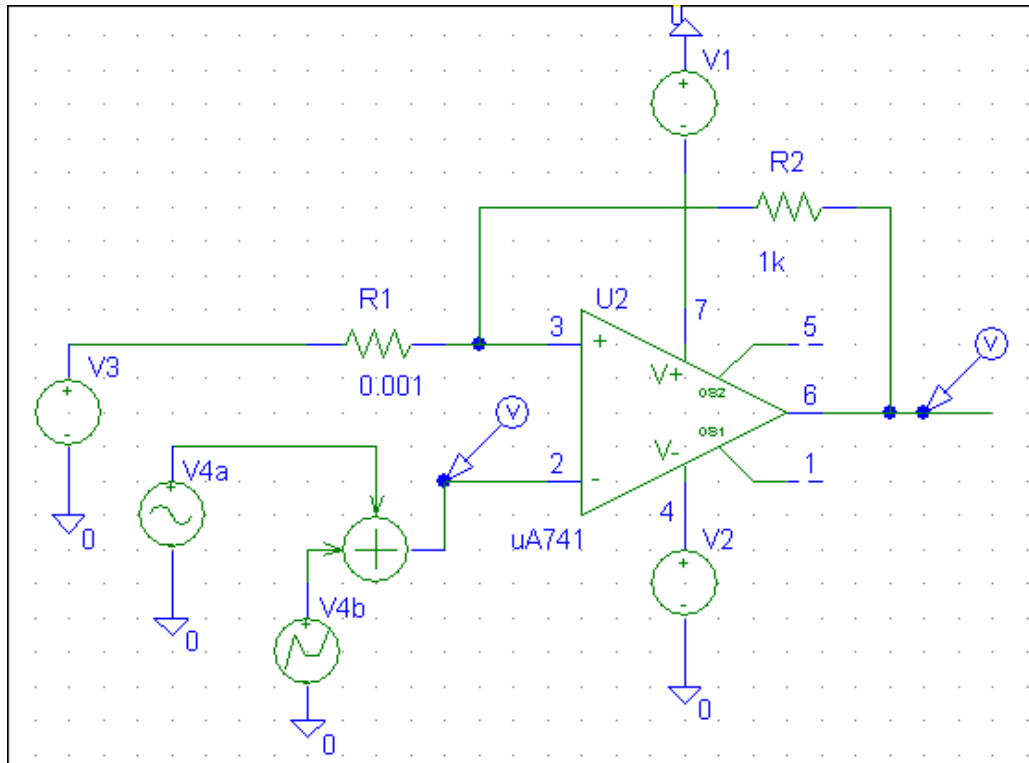
$$V_{OM} \cong 8,5V$$

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

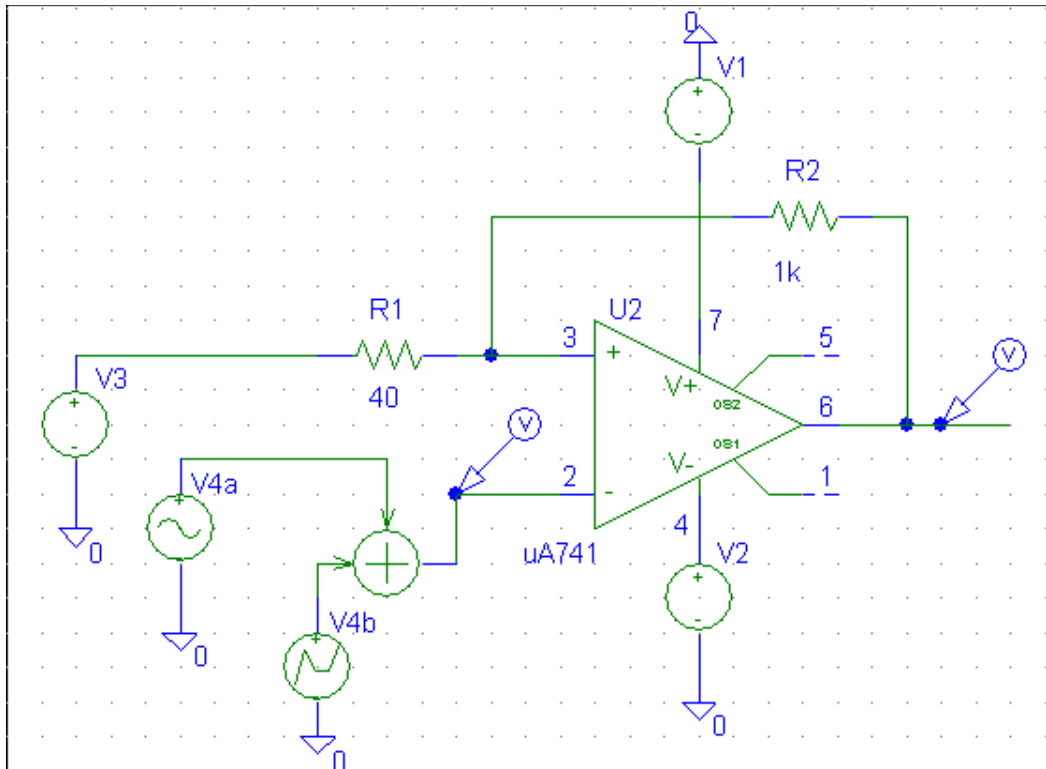
$$V_{OM} \cong 8,5V$$

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)

- amplificare in tensiune
- tensiune de intrare de offset
- curenti de polarizare a intrarilor
- curent de intrare de offset
- impedanta de intrare
- domeniul tensiunii de intrare de mod comun
- excursia maxima a tensiunii de iesire
- curentul maxim de iesire
- factor de rejectie a tensiunii de mod comun
- factor de rejectie a tensiunii de alimentare
- impedanta de iesire
- frecventa de amplificare unitara
- slew-rate

## Ordin de marime

$$a > 10^5$$

$$V_{IO} = 2\text{mV}$$

$$I_B = 80 \text{ nA}$$

$$I_{IO} = 5\text{nA}$$

$$R_i = 2\text{M}\Omega$$

$$[V_{ICmin}, V_{ICmax}]$$

$$[V_{Omin}, V_{Omax}]$$

$$I_{Omax} \text{ (zeci mA)}$$

$$\text{CMRR} = 80\text{dB}$$

$$\text{PSRR} = 80\text{-}120\text{dB}$$

$$R_O = 75\Omega$$

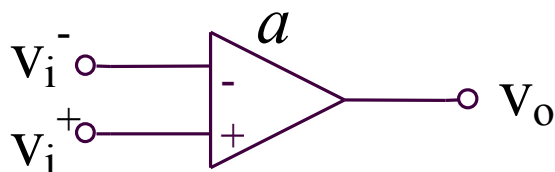
$$f_U = 1\text{MHz}$$

$$\text{SR} = (0,2\text{-}1)\text{V}/\mu\text{s}$$

## 2.4. Deviati 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:

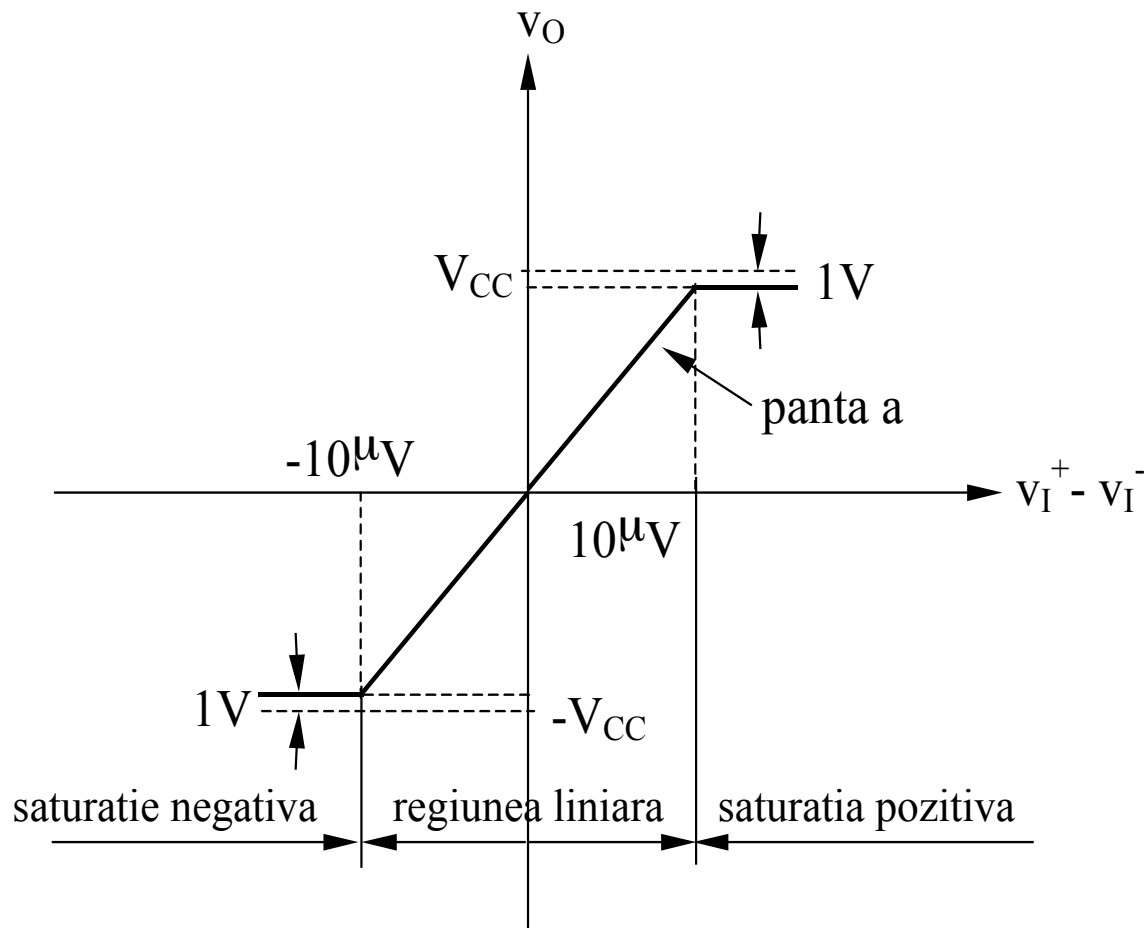
$$v_o = a(v_I^+ - v_I^-)$$

In saturatia negativa:

$$v_o \cong -(V_{CC} - 1V)$$

In saturatia pozitiva:

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

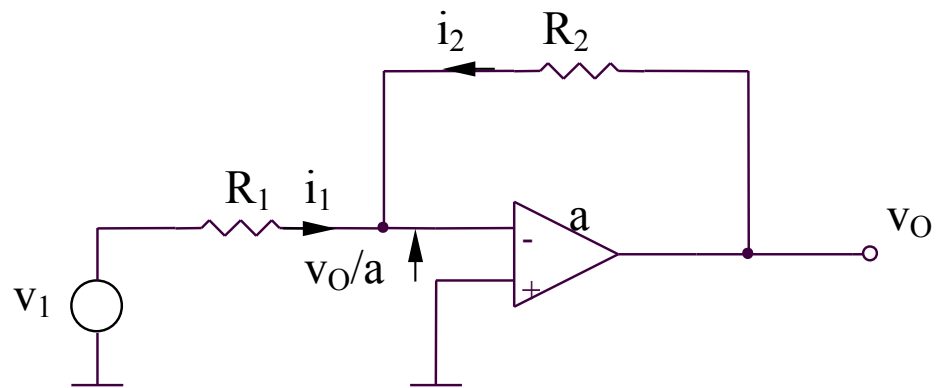




## 2.4. Deviati de la idealitate si limitari ale AO real

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

#### Exemplu 2: Amplificatorul inversor



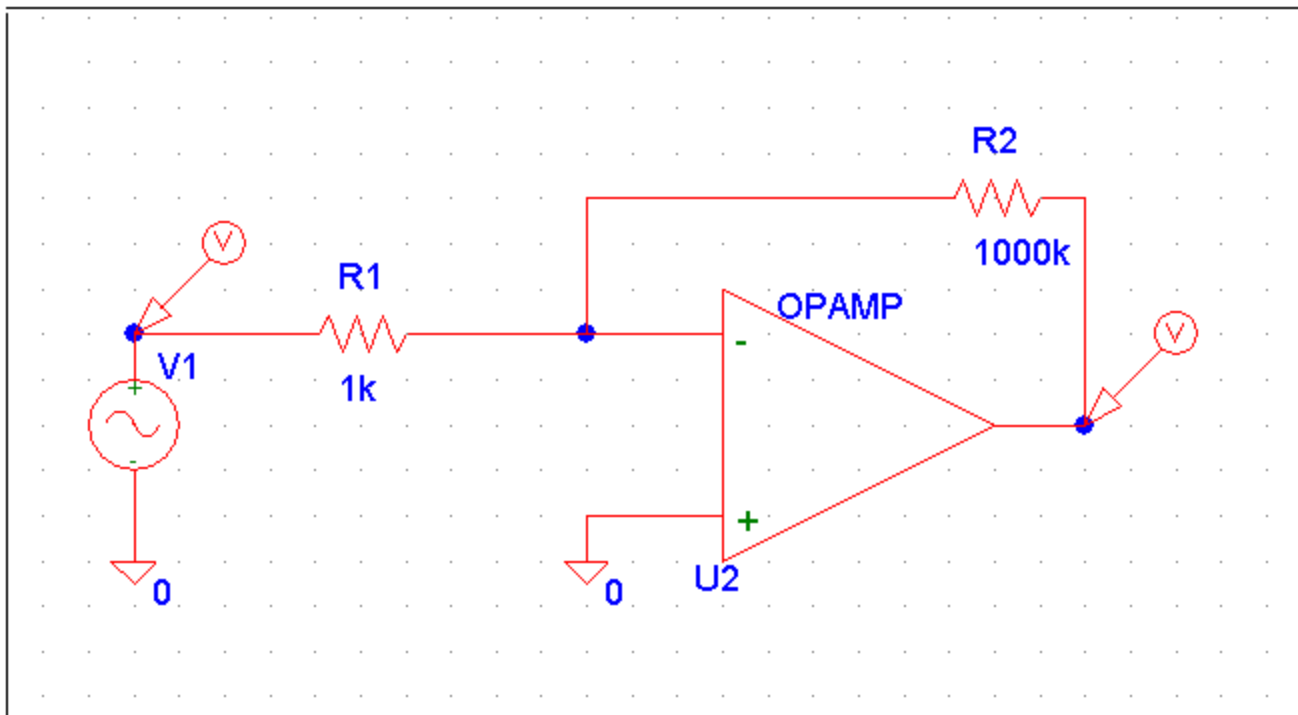
$$\frac{v_1 + \frac{v_O}{a}}{R_1} + \frac{v_O + \frac{v_O}{a}}{R_2} = 0 \Rightarrow$$

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

**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)

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

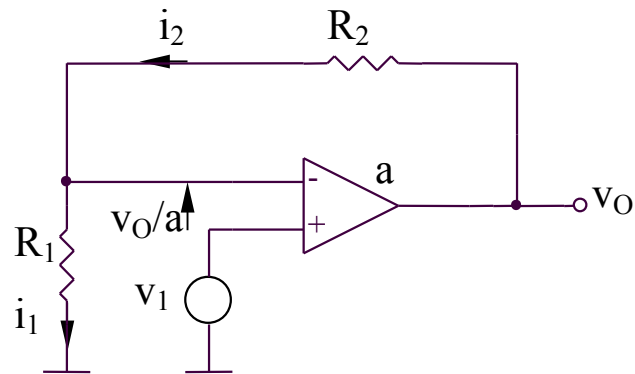
$$A_{real} = -10^3 \frac{1}{1 + \frac{1}{10^3} \left( 1 + 10^3 \right)}$$

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

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

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

#### Exemplu 3: Amplificatorul neinversor



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

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

## 2.4. Deviati 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.

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

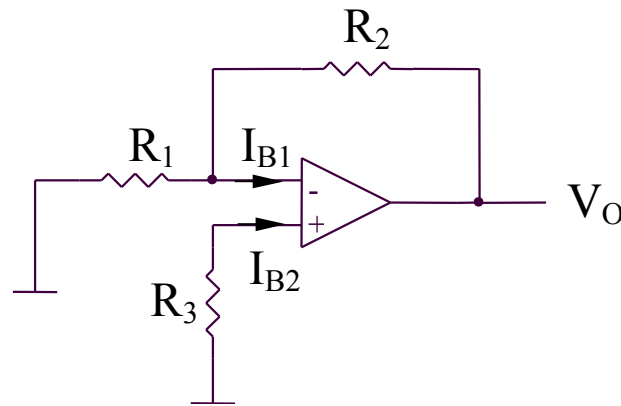
Valori tipice:

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

## 2.4. Deviati 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  $R_3 = R_1 // R_2 = \frac{R_1 R_2}{R_1 + R_2}$

se obtine:

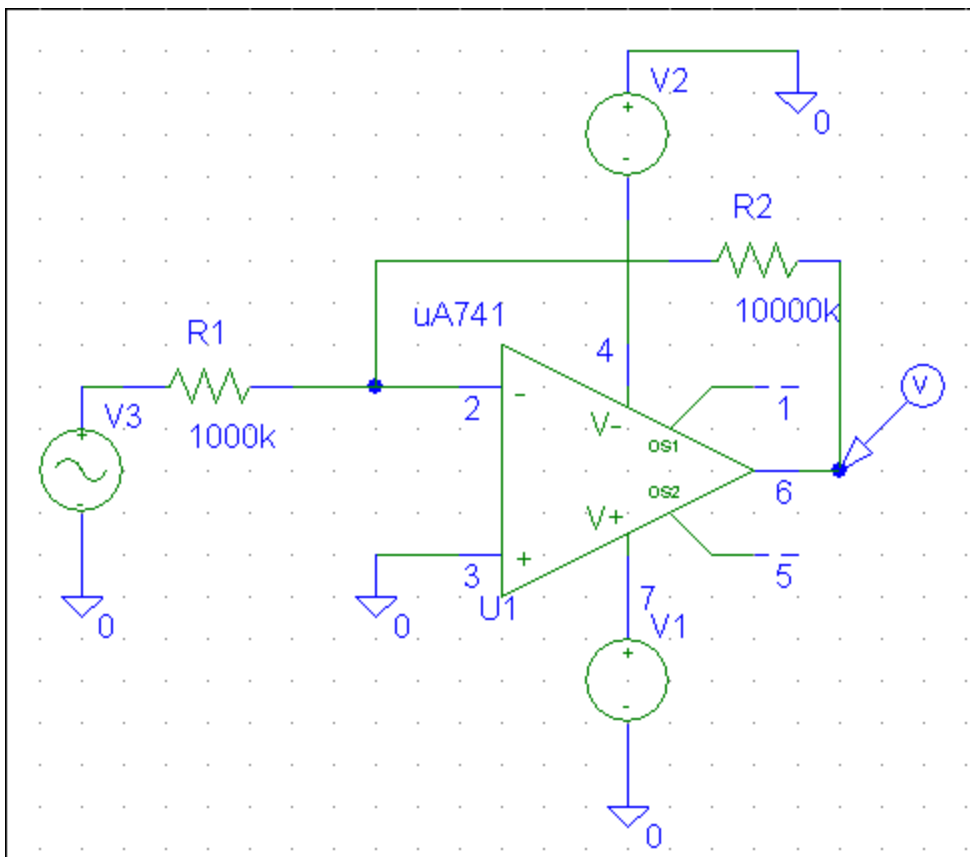
$$V_O = 0$$

**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  $R_3$  )



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

$$V_{AMPL} = 5mV$$

$$f = 1kHz$$

$$I_B = 80nA$$

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

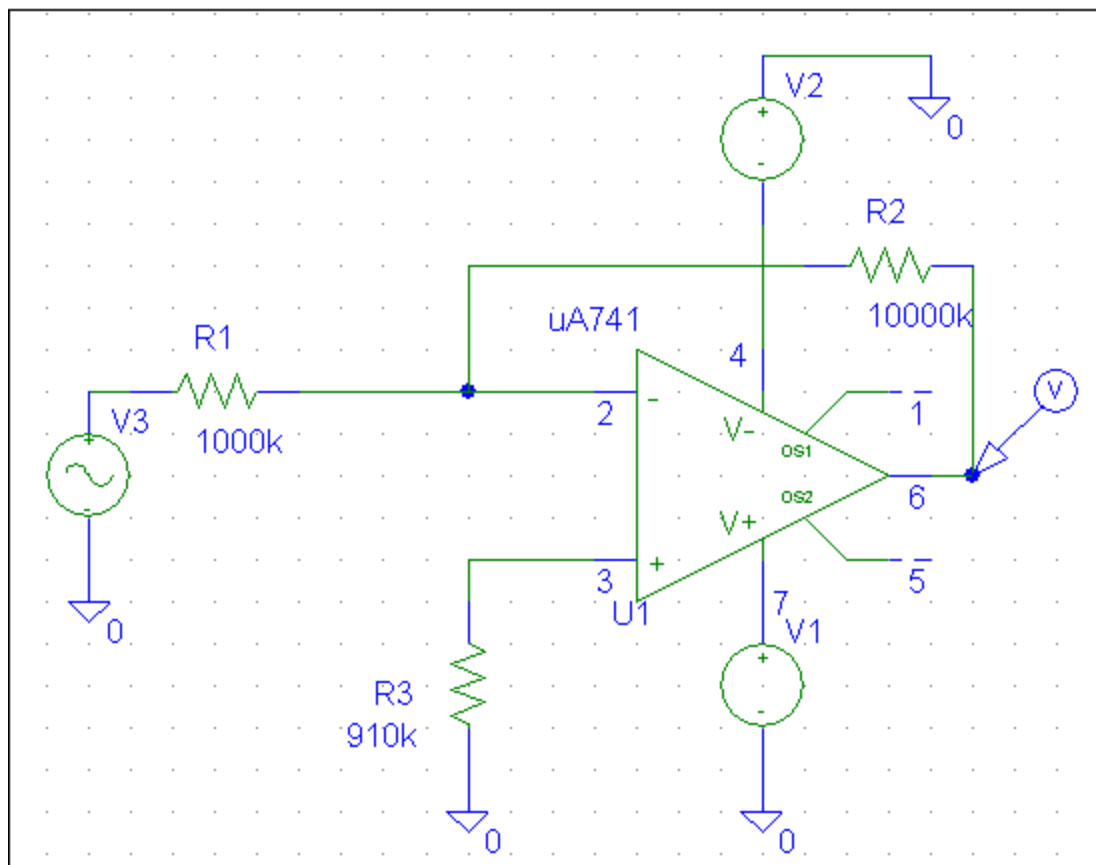
$$R_3 = 0 \Rightarrow \Delta V_O = I_{B1}R_2$$

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

$$\Delta V_O = 800mV$$

# 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  $R_3$ )



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

$$V_{AMPL} = 5mV$$

$$f = 1kHz$$

$$I_B = 80nA$$

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

$$R_3 = R_1 // R_2$$

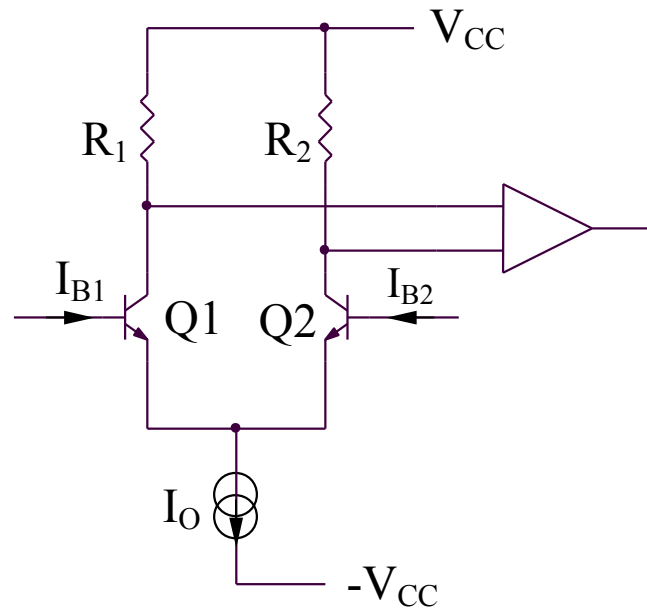
$$R_3 = 1M\Omega // 10M\Omega$$

$$R_3 \cong 910k\Omega$$

$$\Rightarrow \Delta V_O = 0$$

## 2.4. Deviati 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. Deviati 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.

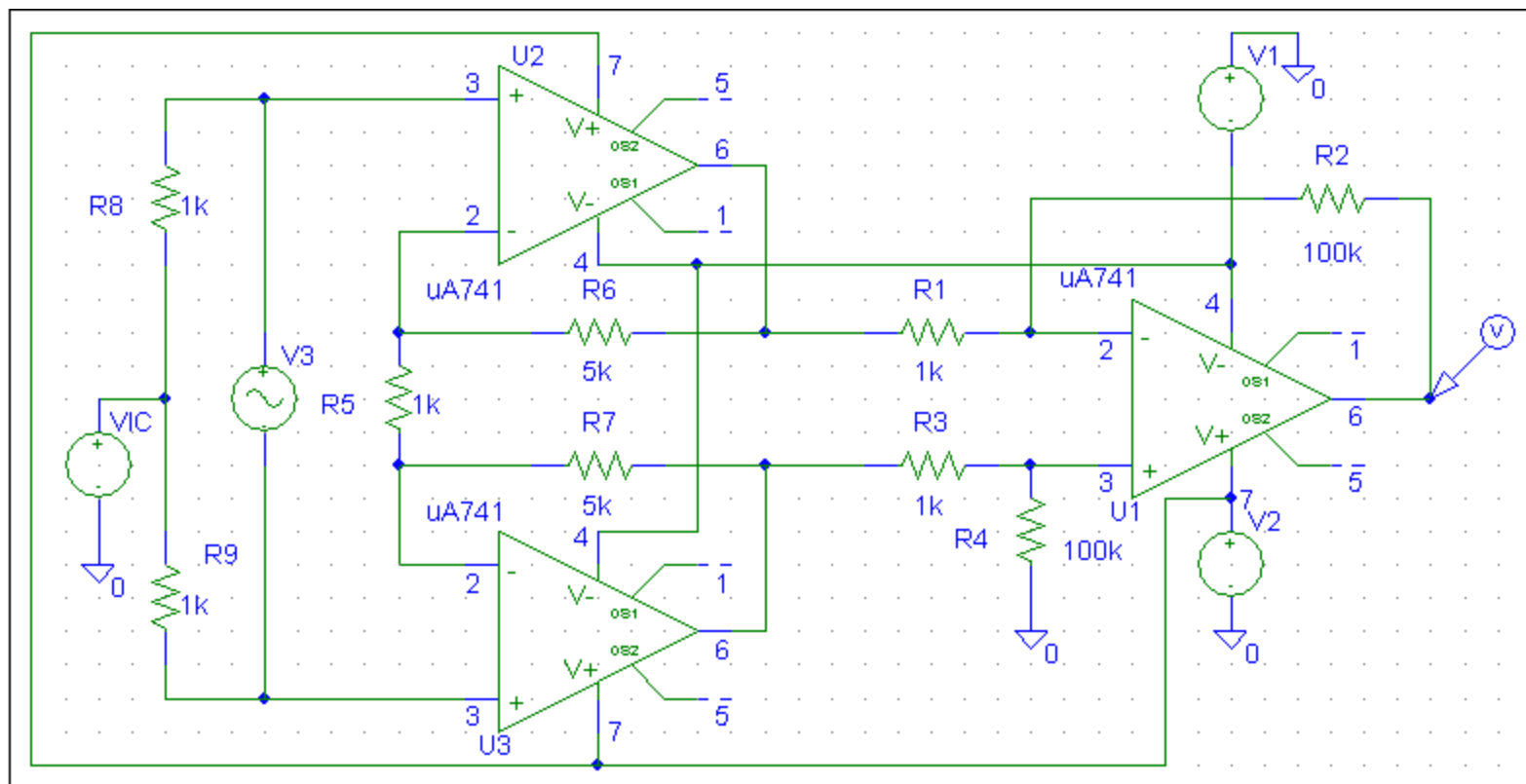
**SIMULARI pentru evaluarea limitarilor introduse de  $[v_{ICmin} v_{ICmin}]$**

## 2.4. Deviati 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  $v_{ICmin} < v_{IC} < v_{ICmax}$



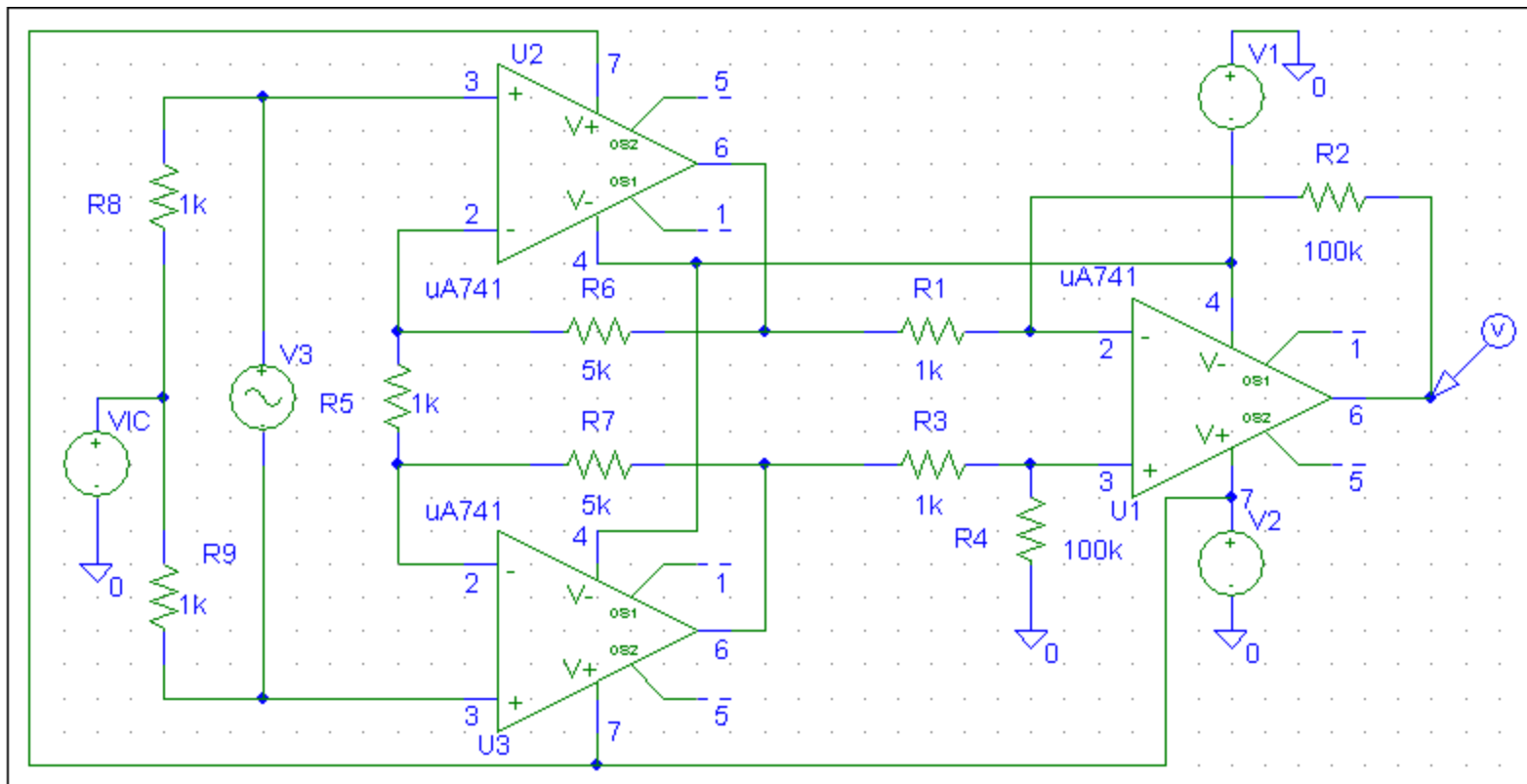
$$v_3(t) = V_{AMPL} \sin(2\pi f t) \quad V_{AMPL} = 1mV; f = 100Hz; v_{IC} = 0 \quad A = \frac{v_o}{v_3} = 1100$$

## 2.4. Deviati 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 $v_{IC} > v_{ICmax}$



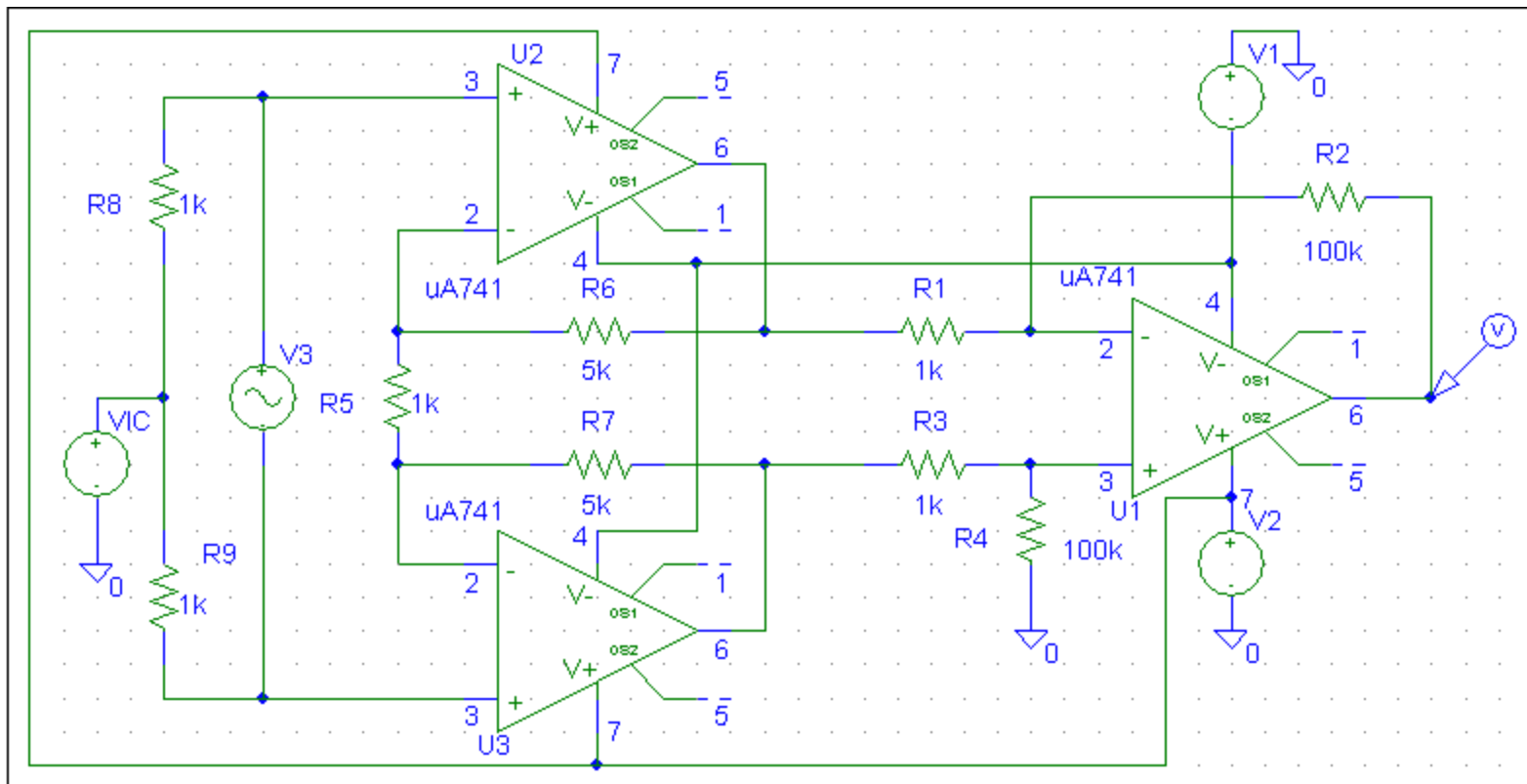
$$v_3(t) = V_{AMPL} \sin(2\pi f t) \quad V_{AMPL} = 1mV; f = 100Hz; v_{IC} = 9V \quad A = \frac{v_o}{v_3} = 1100$$

## 2.4. Deviati 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 $v_{IC} < v_{ICmin}$



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



## **2.4. Deviati de la idealitate si limitari ale AO real**

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

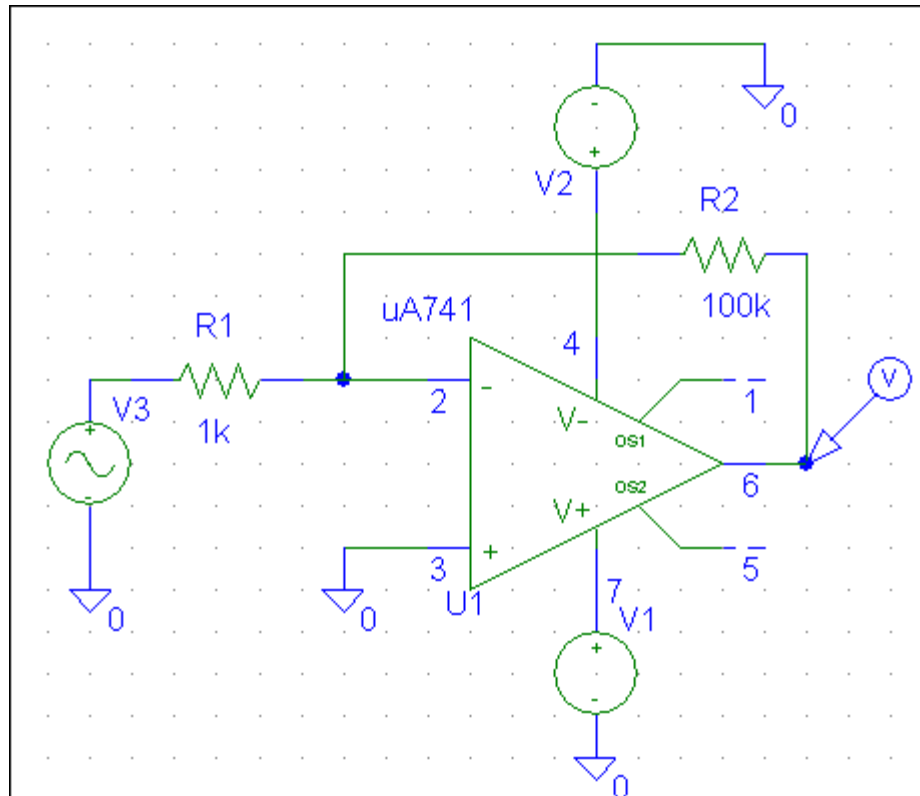
Reprezinta limitele (minima si maxima) intre care poate evolua tensiunea de iesire a AO.

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<sub>Omin</sub>, v<sub>Omax</sub> ]**

# SIMULARI pentru evaluarea excursiei maxime a tensiunii de iesire [v<sub>Omin</sub>, v<sub>Omax</sub>]

## SIM 2.21: v<sub>3</sub> (t), v<sub>O</sub> (t)



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

$$V_{AMPL} = 200mV$$

$$f = 1kHz$$

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

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

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

## **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.

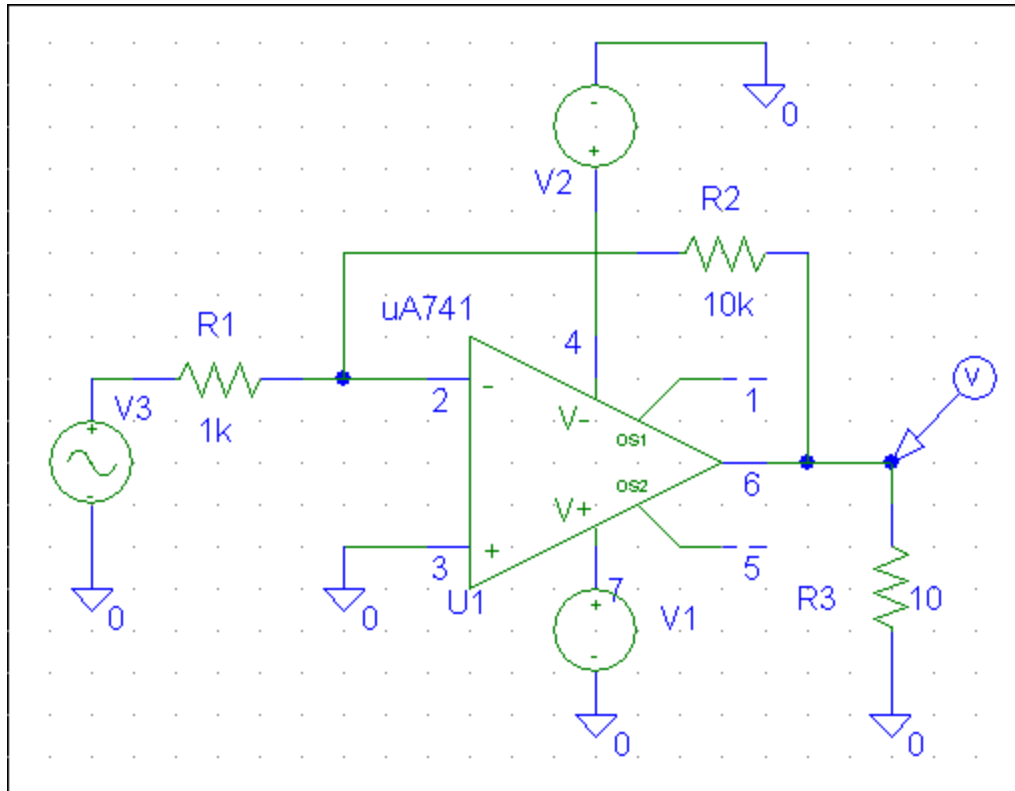
**SIMULARI pentru evaluarea curentului maxim de iesire (  $I_{Omax}$  )**

## 2.4. Deviati 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: $v_3(t)$ , $v_O(t)$



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

$$V_{AMPL} = 100mV$$

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

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

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

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

## **2.4. Deviati 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.

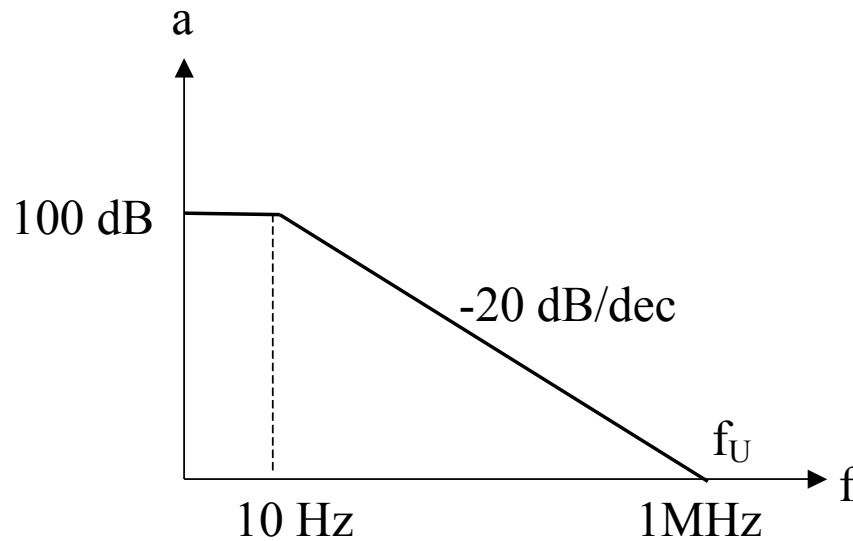
### **2.4.8. Factorul de rejectie a tensiunii de alimentare (PSRR)**

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

## 2.4. Deviati 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.



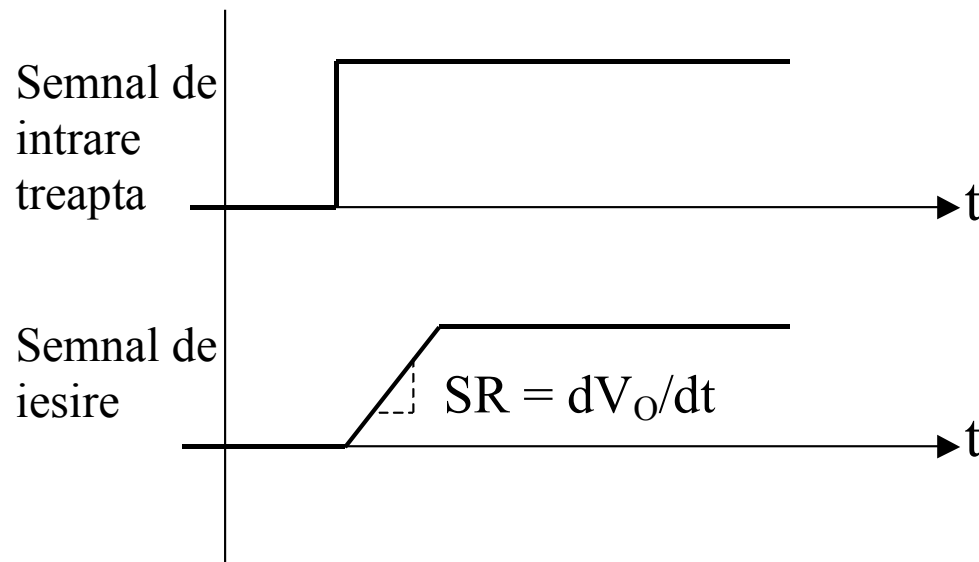
$f_U$  – in domeniul 1MHz – 100MHz



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

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

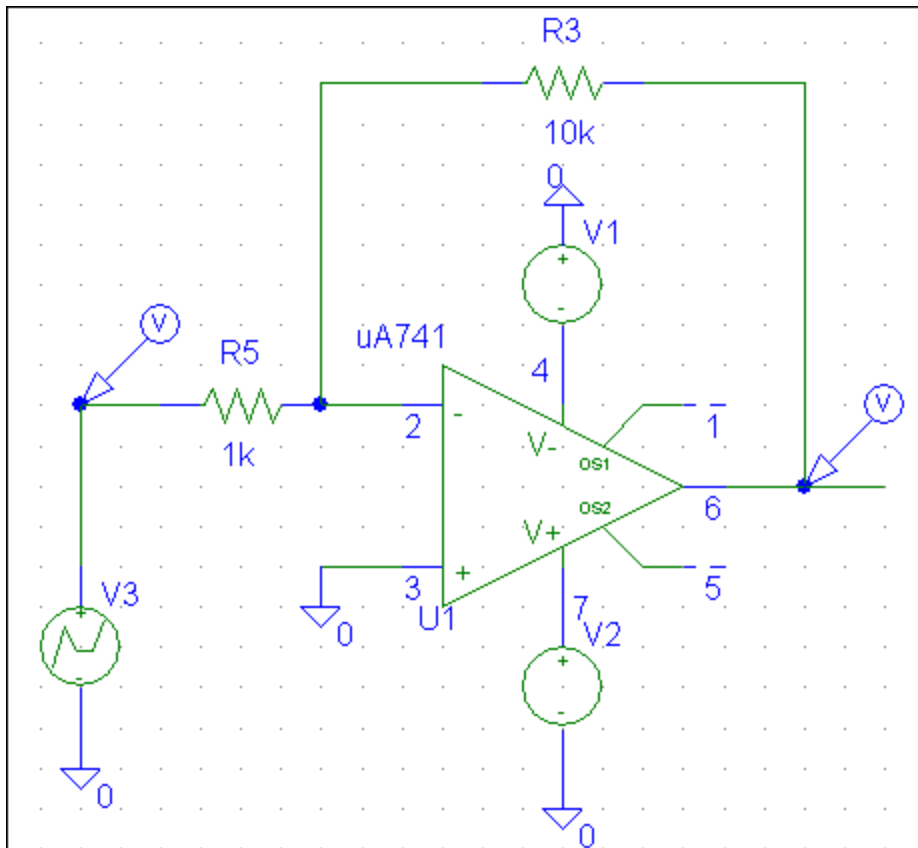
Reprezinta panta maxima a raspunsului tranzitoriu pentru un semnal de intrare de tip treapta.



**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: $v_3(t)$ , $v_O(t)$

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

$$V_{AMPL} = 1V$$

$$f = 100kHz$$

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

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

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

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

