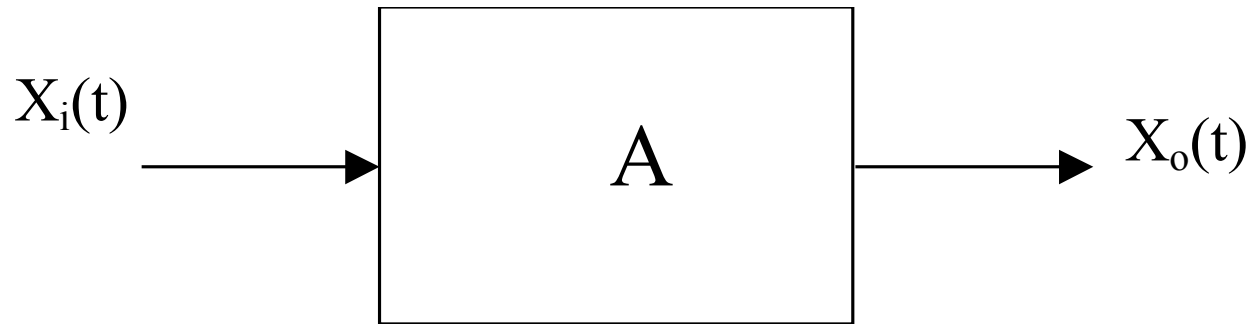


Capitolul 2

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

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

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

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

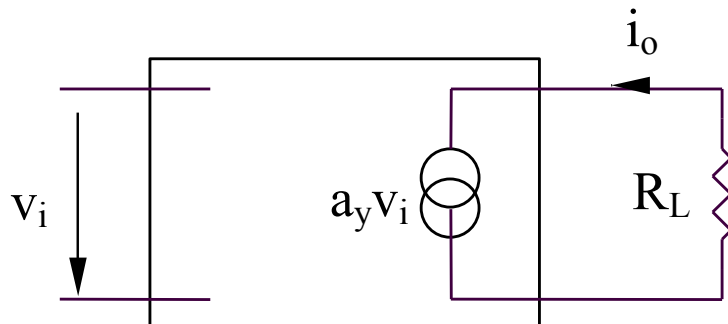
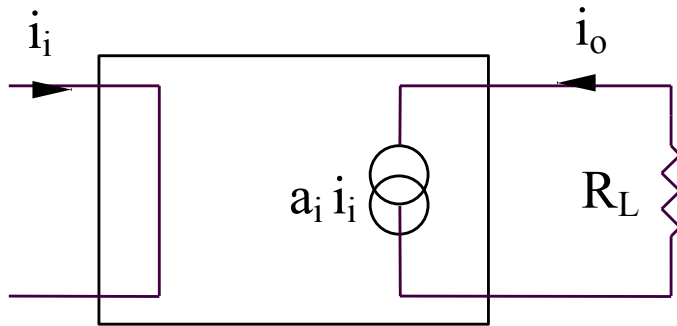
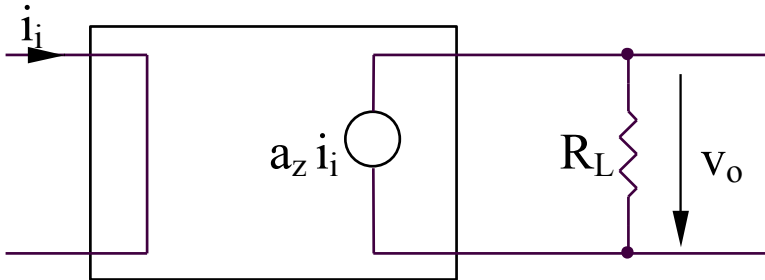
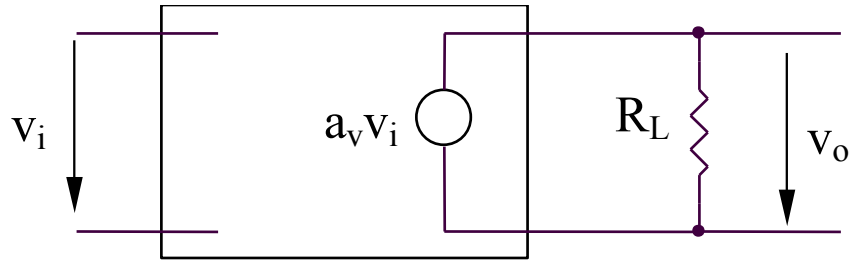
$$A_z = \frac{v_O}{i_I}$$

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

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

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

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

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

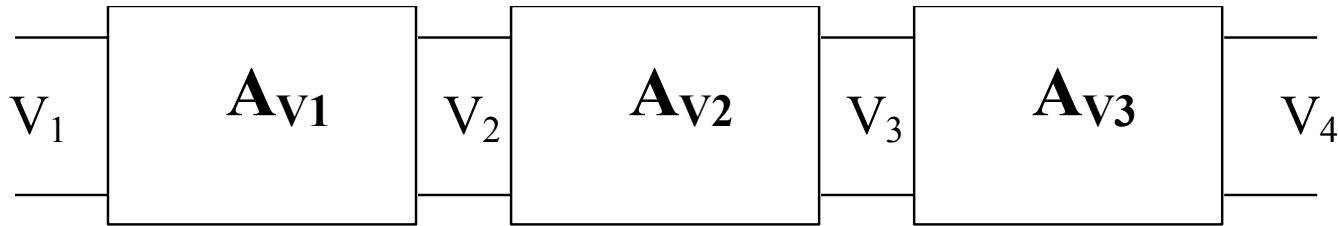
Amplificatorul de curent

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

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



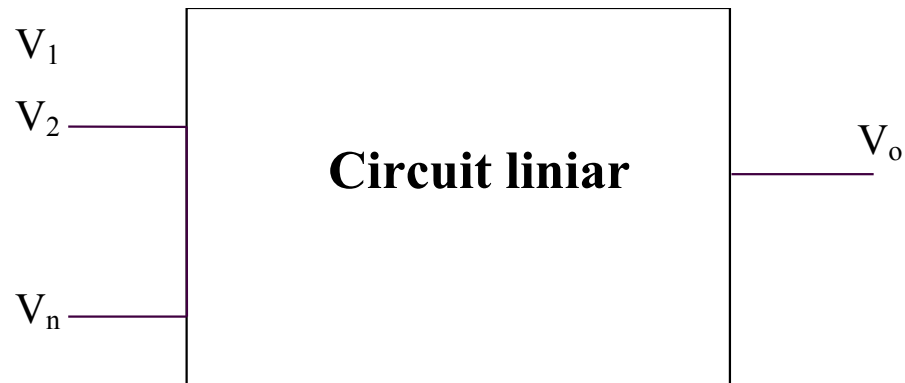
$$A_V = \frac{V_4}{V_1} = A_{V1}A_{V2}A_{V3}$$

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

2.2. Aplicatii ale amplificatoarelor operationale

2.2. Aplicatii ale amplificatoarelor operationale

Teorema superpozitiei

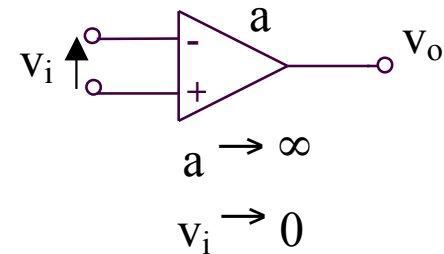


$$V_o = V_o \Big|_{\substack{V_1 \neq 0 \\ V_2 = V_3 = \dots V_n = 0}} + V_o \Big|_{\substack{V_2 \neq 0 \\ V_1 = V_3 = \dots V_n = 0}} + \dots + V_o \Big|_{\substack{V_n \neq 0 \\ V_1 = V_2 = \dots V_{n-1} = 0}}$$

2.2. Aplicatii ale amplificatoarelor operationale

Un amplificator operational ideal este caracterizat prin:

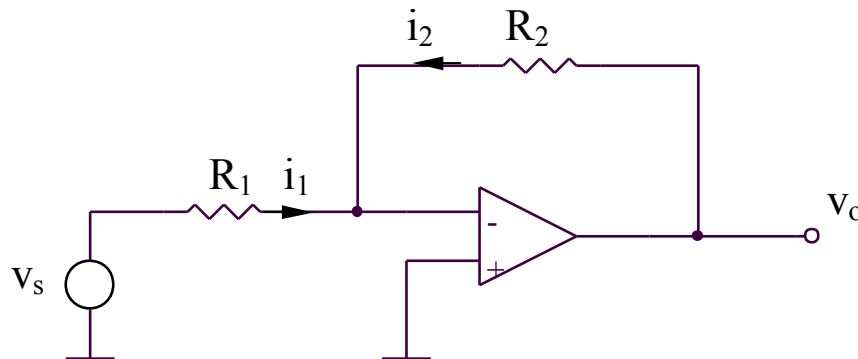
- amplificare in tensiune infinita
- impedanta de intrare infinita
- impedanta de iesire nula



In consecinta:

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

2.2.1. Amplificatorul inversor

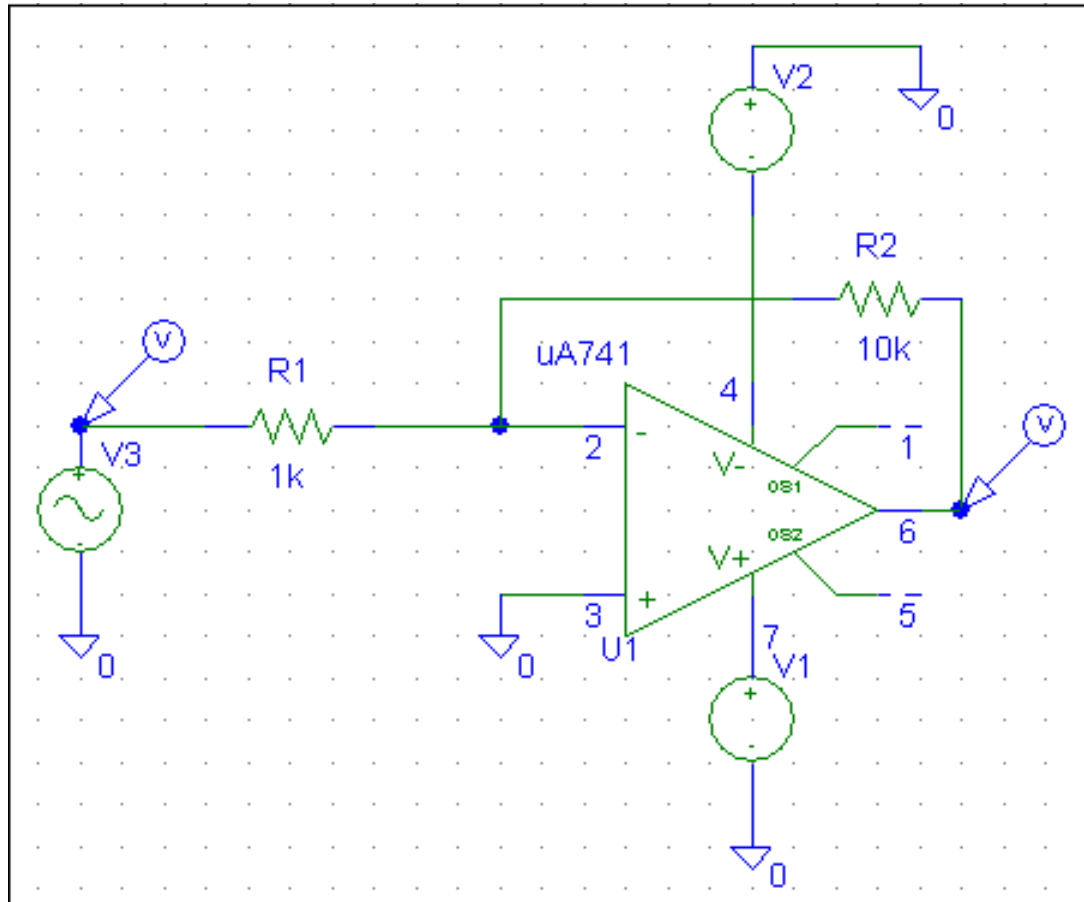


$$i_1 = -i_2$$
$$\frac{v_s}{R_1} = -\frac{v_o}{R_2}$$
$$\Rightarrow A = \frac{v_o}{v_s} = -\frac{R_2}{R_1}$$

SIMULARI pentru amplificatorul inversor

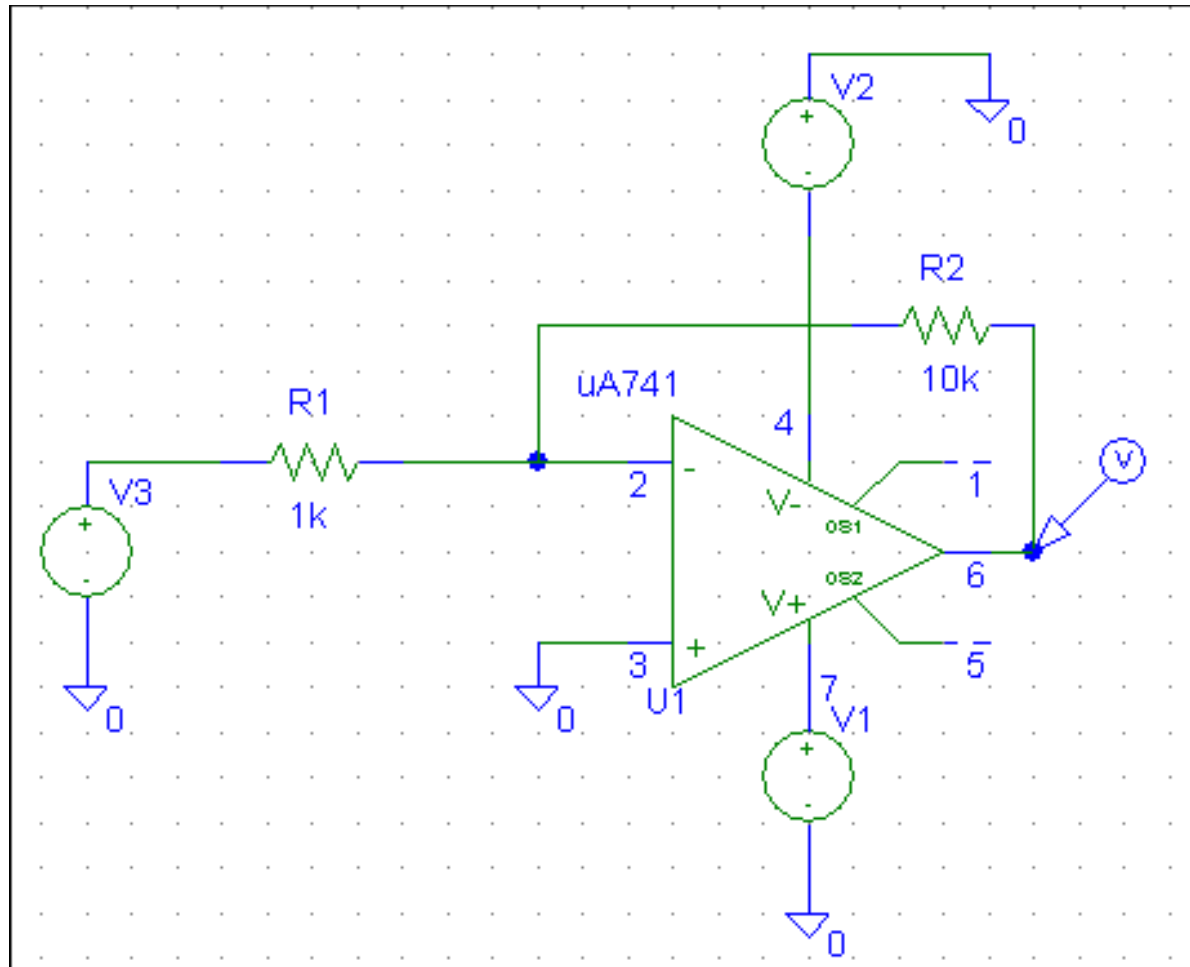
SIMULARI pentru amplificatorul inversor

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

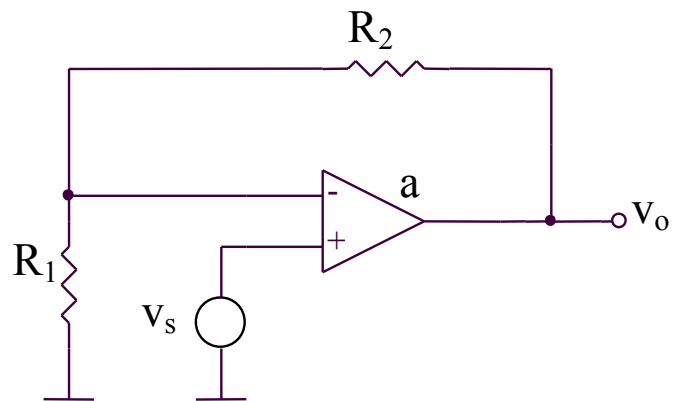


SIMULARI pentru amplificatorul inversor

SIM 2.2: v_O (v_3)



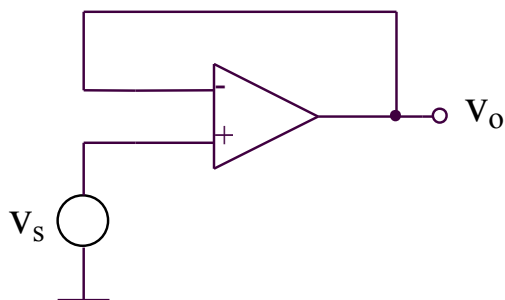
2.2.2. Amplificatorul neinversor



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

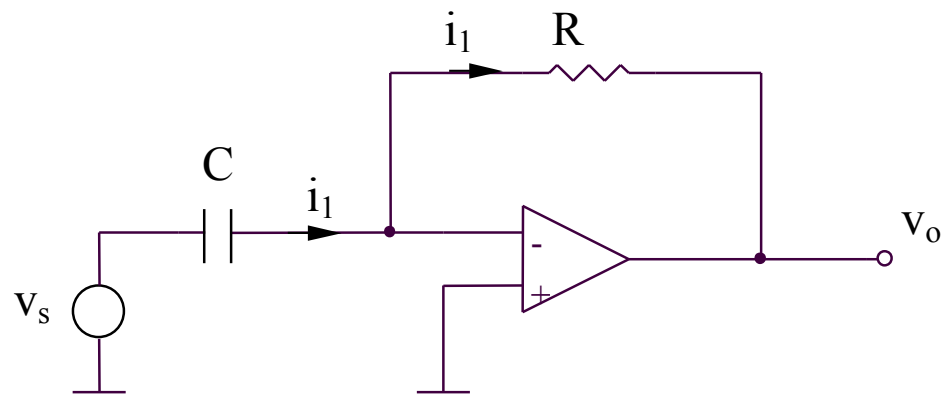
$$A = \frac{v_o}{v_s} = 1 + \frac{R_2}{R_1}$$

2.2.3. Circuitul repetor



$$v_o = v_s$$

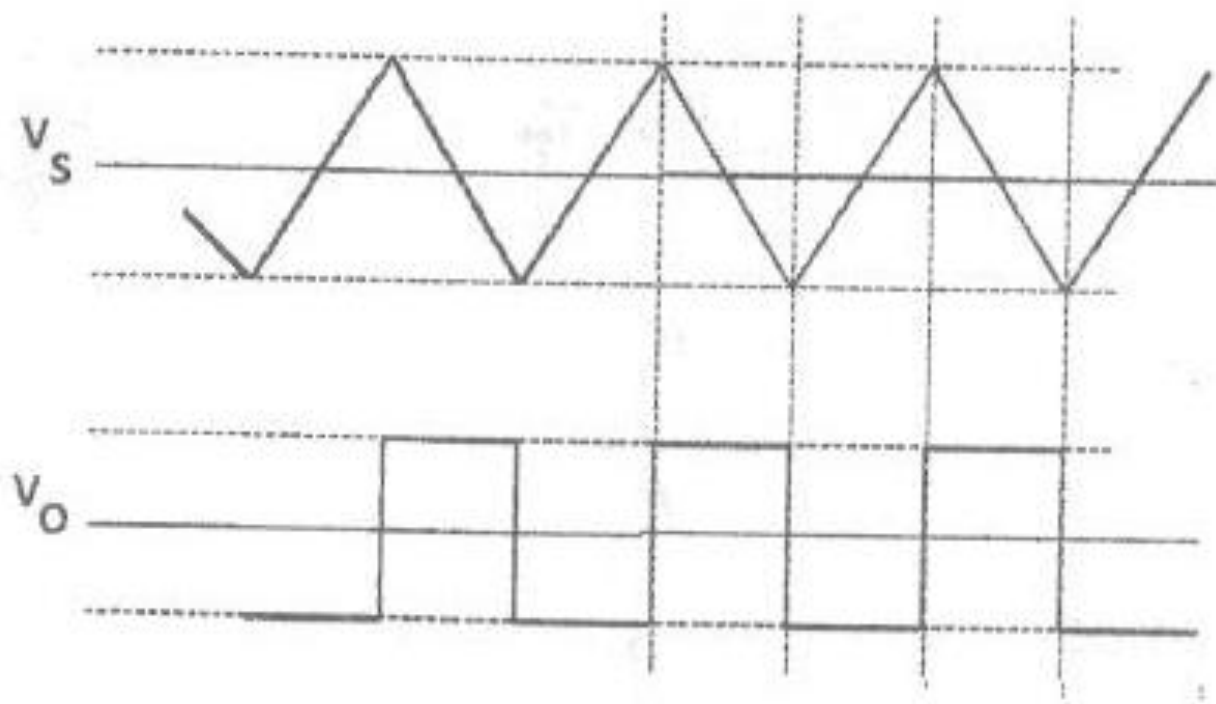
2.2.4. Circuitul de derivare



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

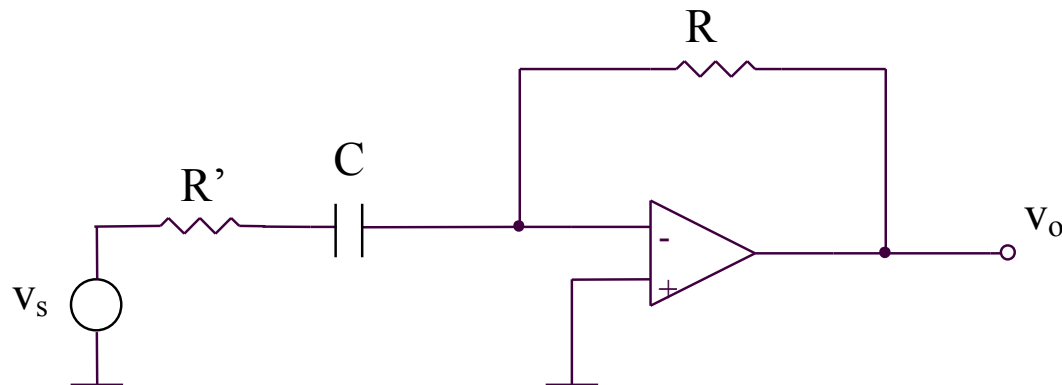
$$v_o = -Ri_1 = -RC \frac{dv_s}{dt}$$

2.2.4. Circuitul de derivare

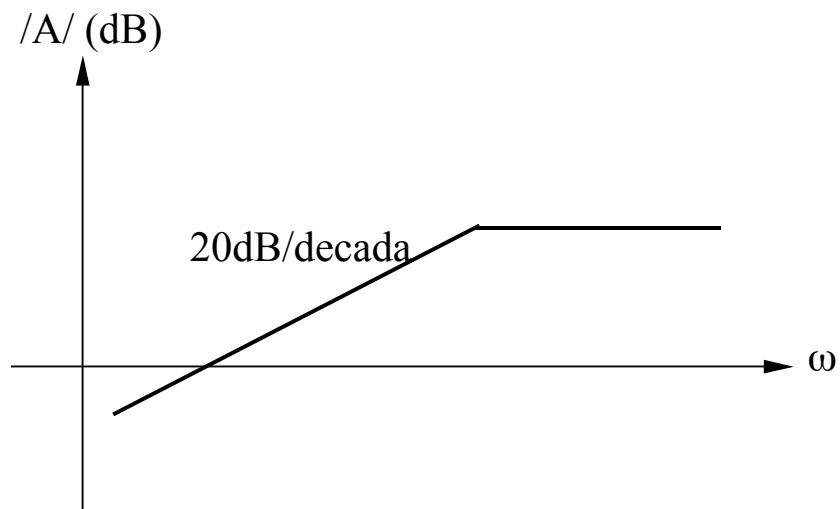


2.2.4. Circuitul de derivare

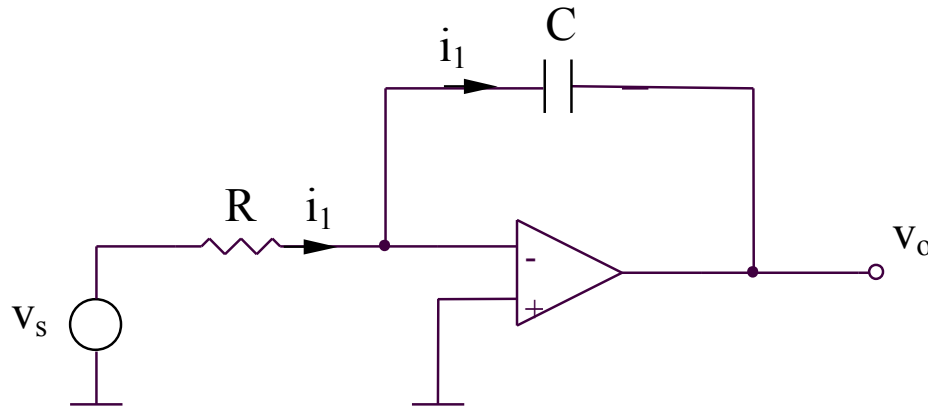
Introducerea R' – pentru cresterea stabilitatii



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



2.2.5. Circuitul de integrare

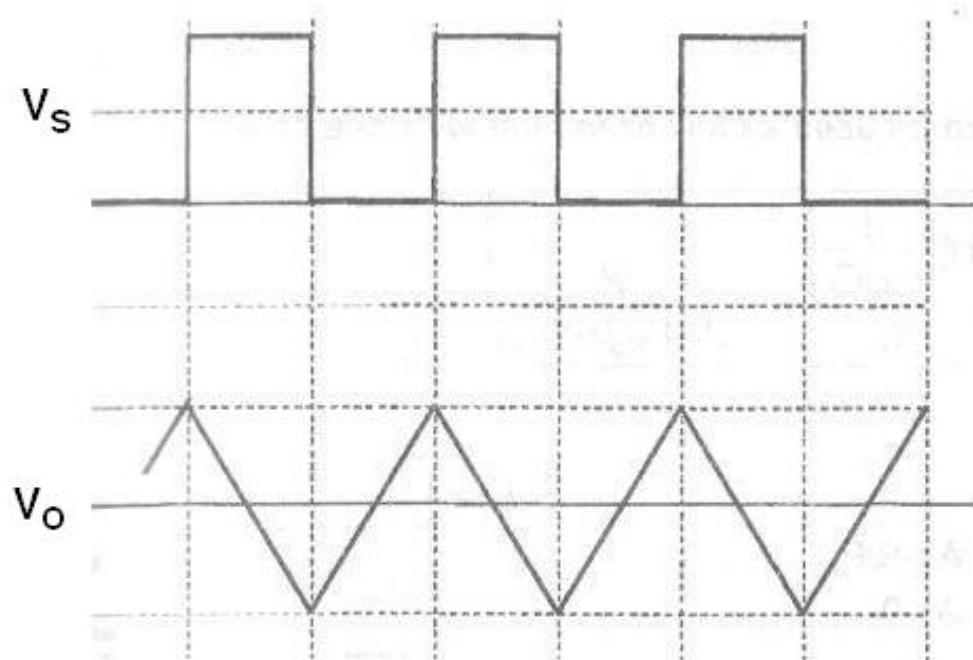


$$i_1 = \frac{v_s(t)}{R}$$

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

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

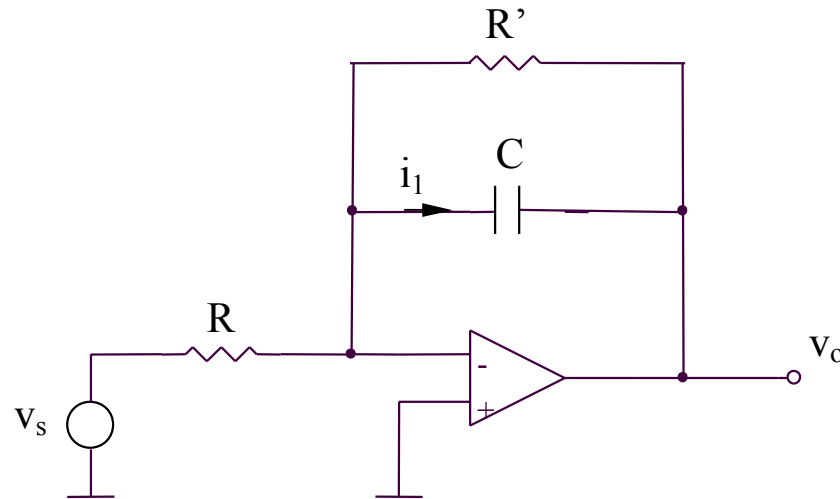
2.2.5. Circuitul de integrare



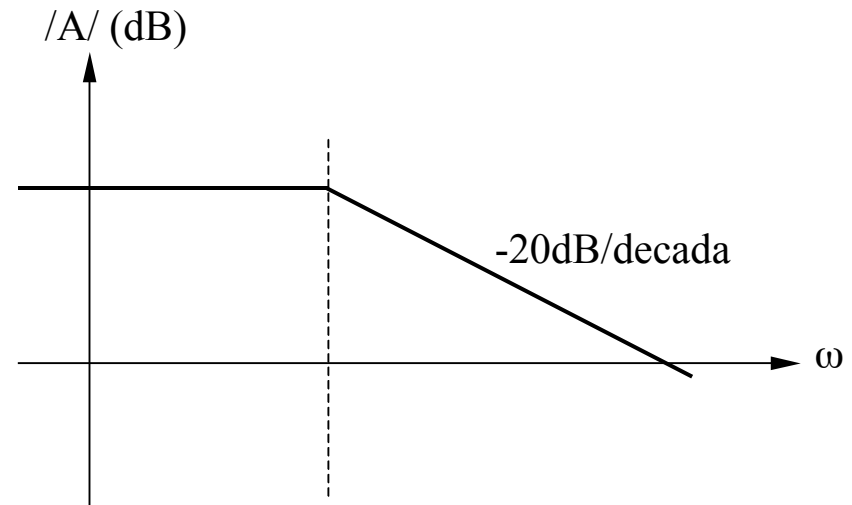
2.2.5. Circuitul de integrare

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

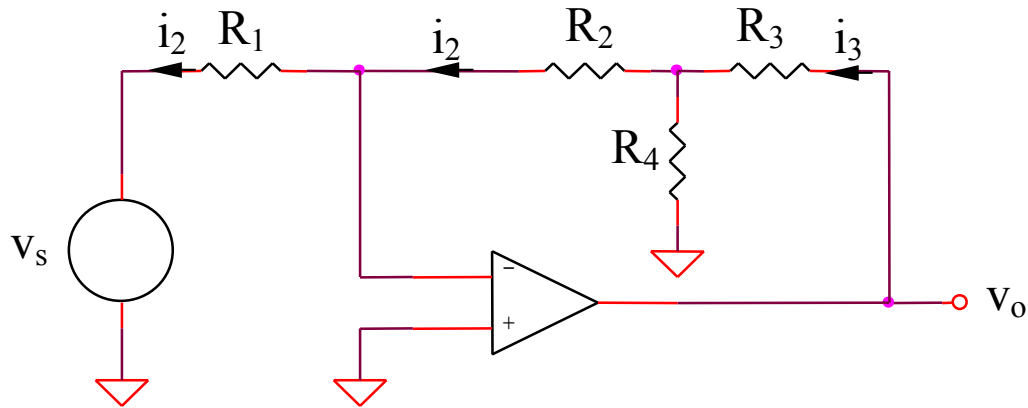
Amplificarea in curent continuu finita, $A_{cc} = - R' / R$



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



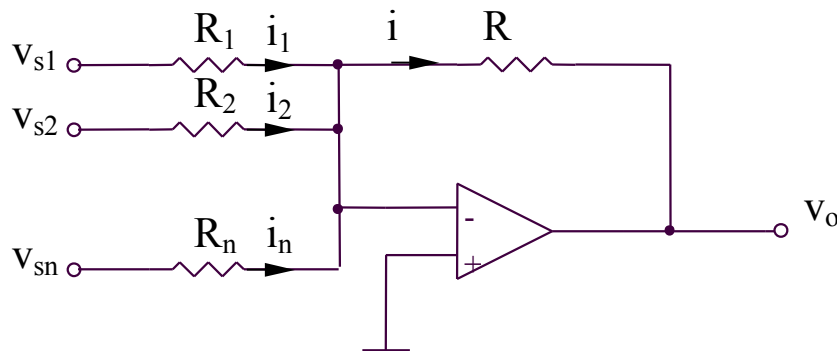
2.2.6. Circuit cu amplificare marita



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

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

2.2.7. Sumatorul inversor



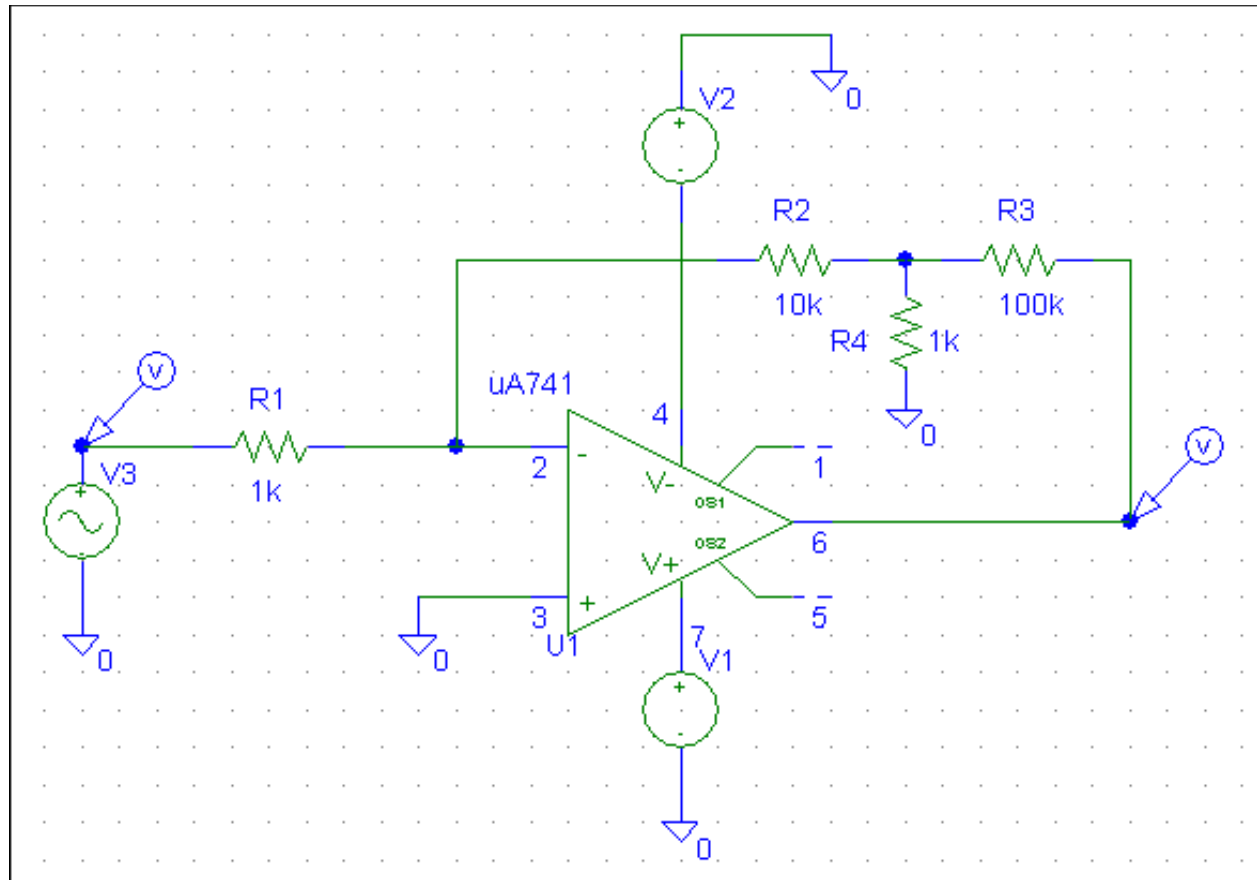
$$i = \sum_{i=1}^n i_i = \sum_{i=1}^n \frac{v_{si}}{R_i}$$

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

SIMULARI pentru circuitul cu amplificare marita

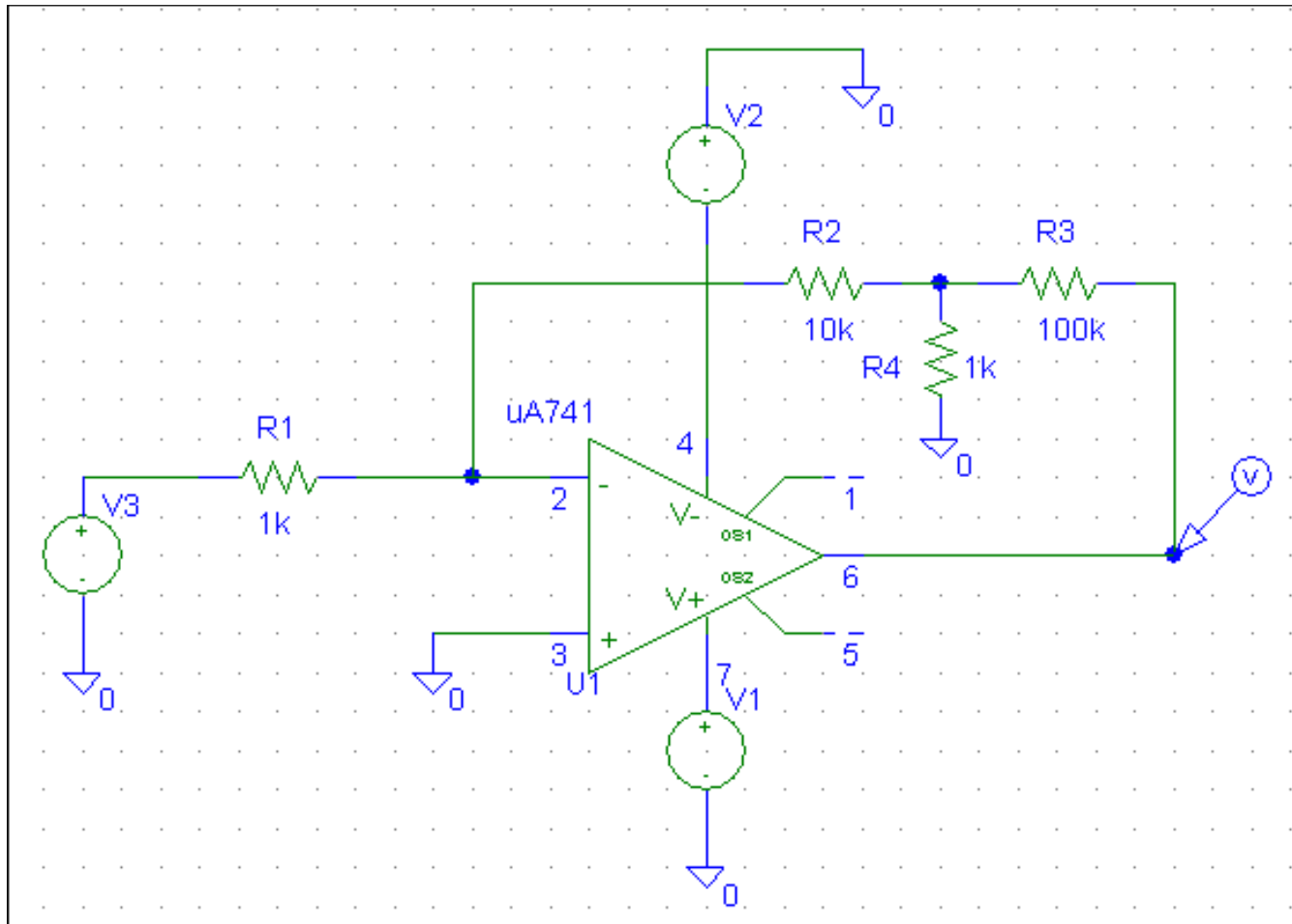
SIMULARI pentru circuitul cu amplificare marita

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



SIMULARI pentru circuitul cu amplificare marita

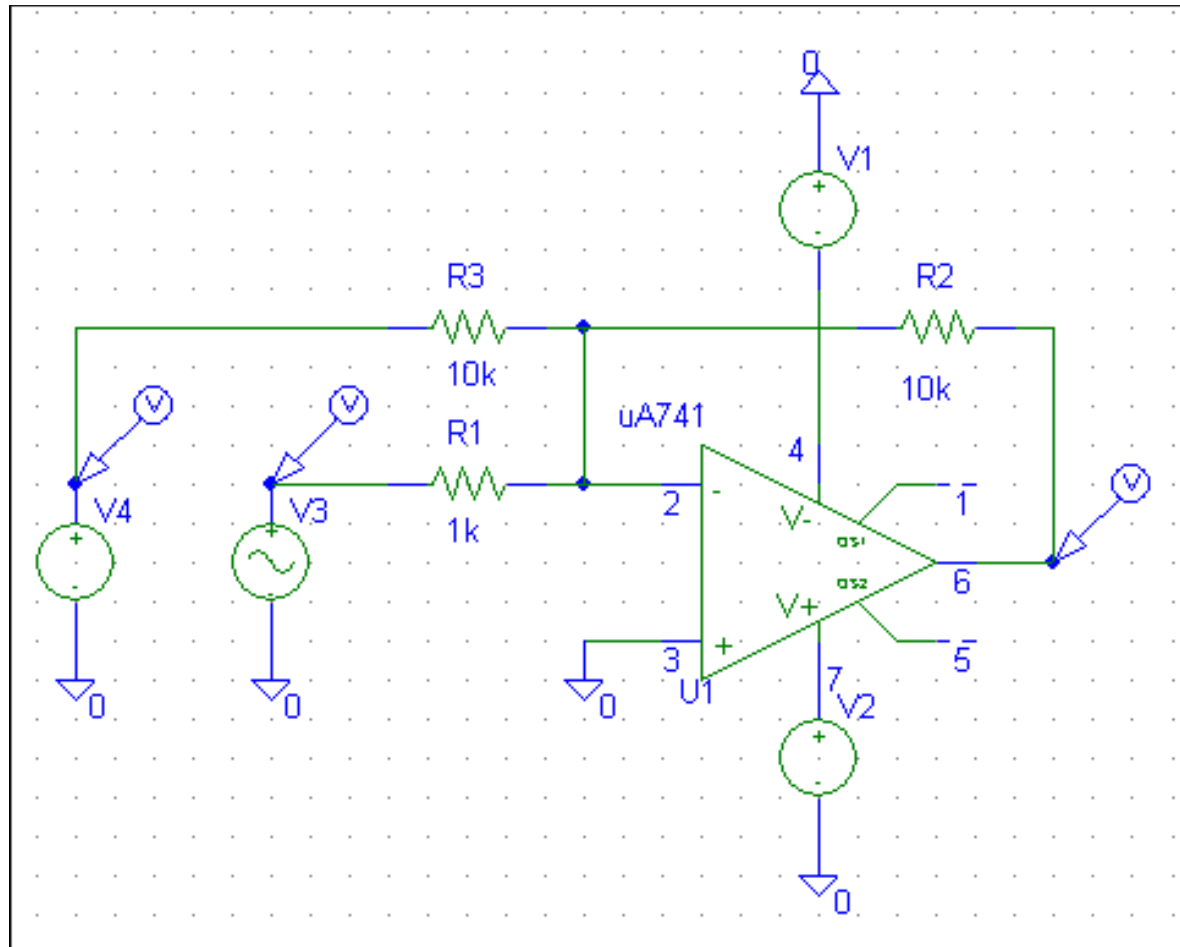
SIM 2.4: v_O (v_3)



SIMULARI pentru sumatorul inversor

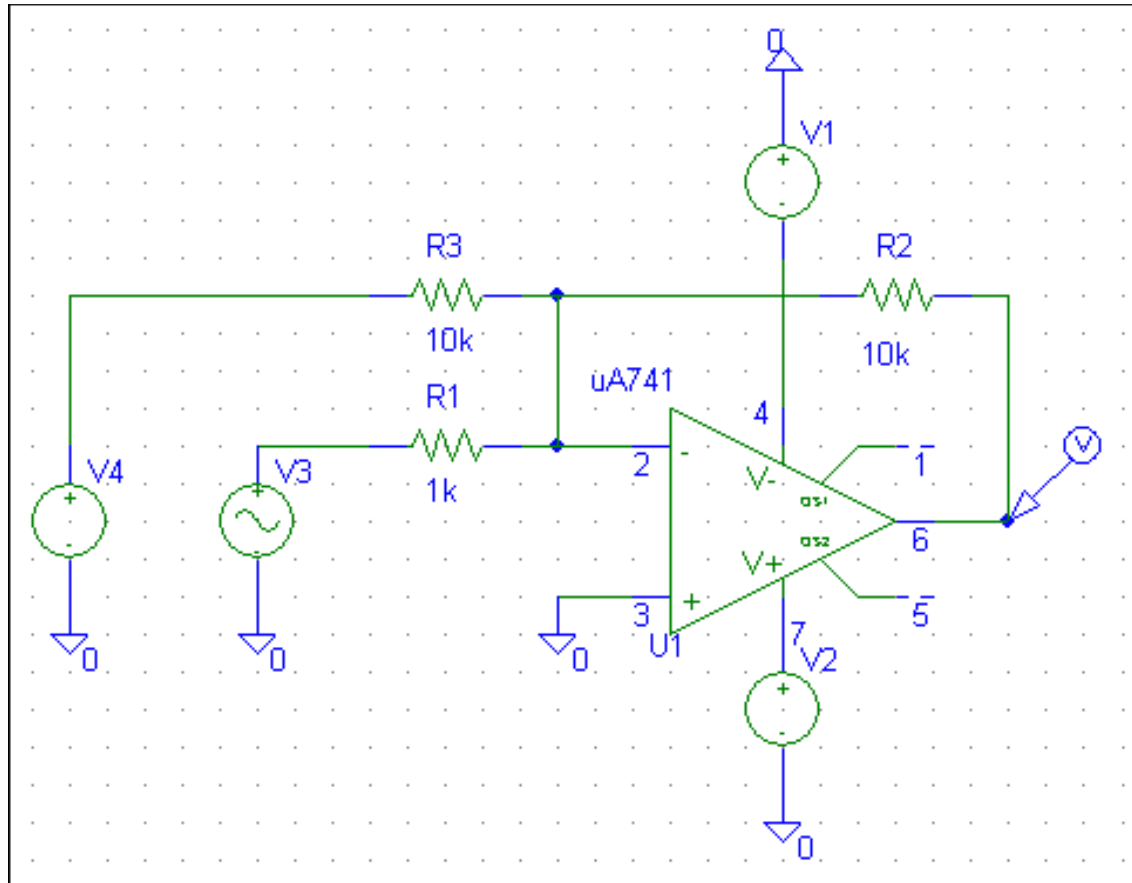
SIMULARI pentru sumatorul inversor

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

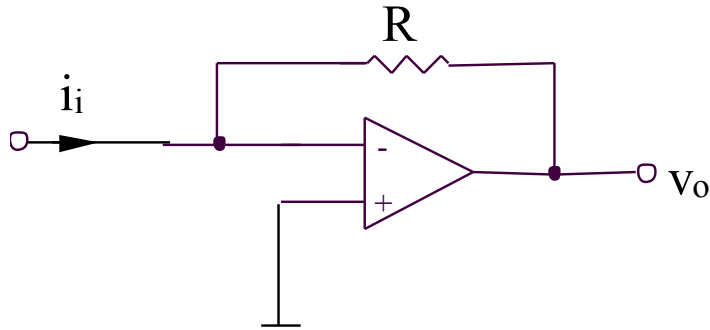


SIMULARI pentru sumatorul inversor

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

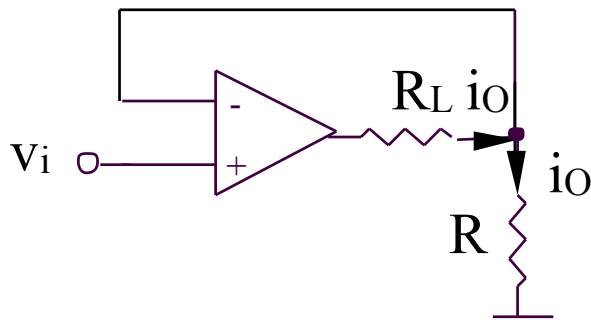


2.2.8. Convertorul curent-tensiune



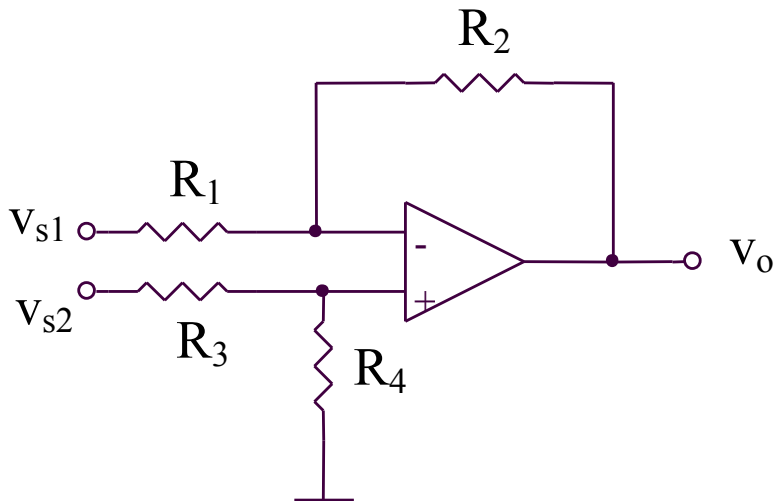
$$v_o = -Ri_i$$

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:

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

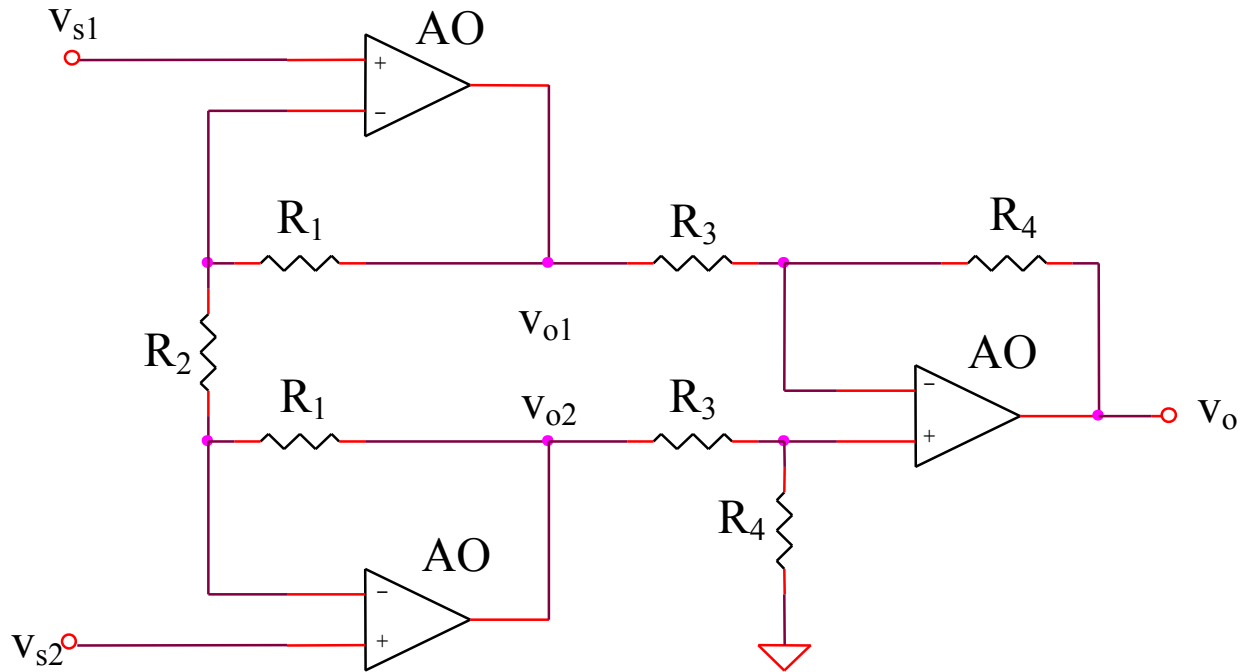
echivalenta cu:

$$R_1 R_4 = R_2 R_3$$

rezultand:

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

2.2.11. Circuitul de diferenta (2)

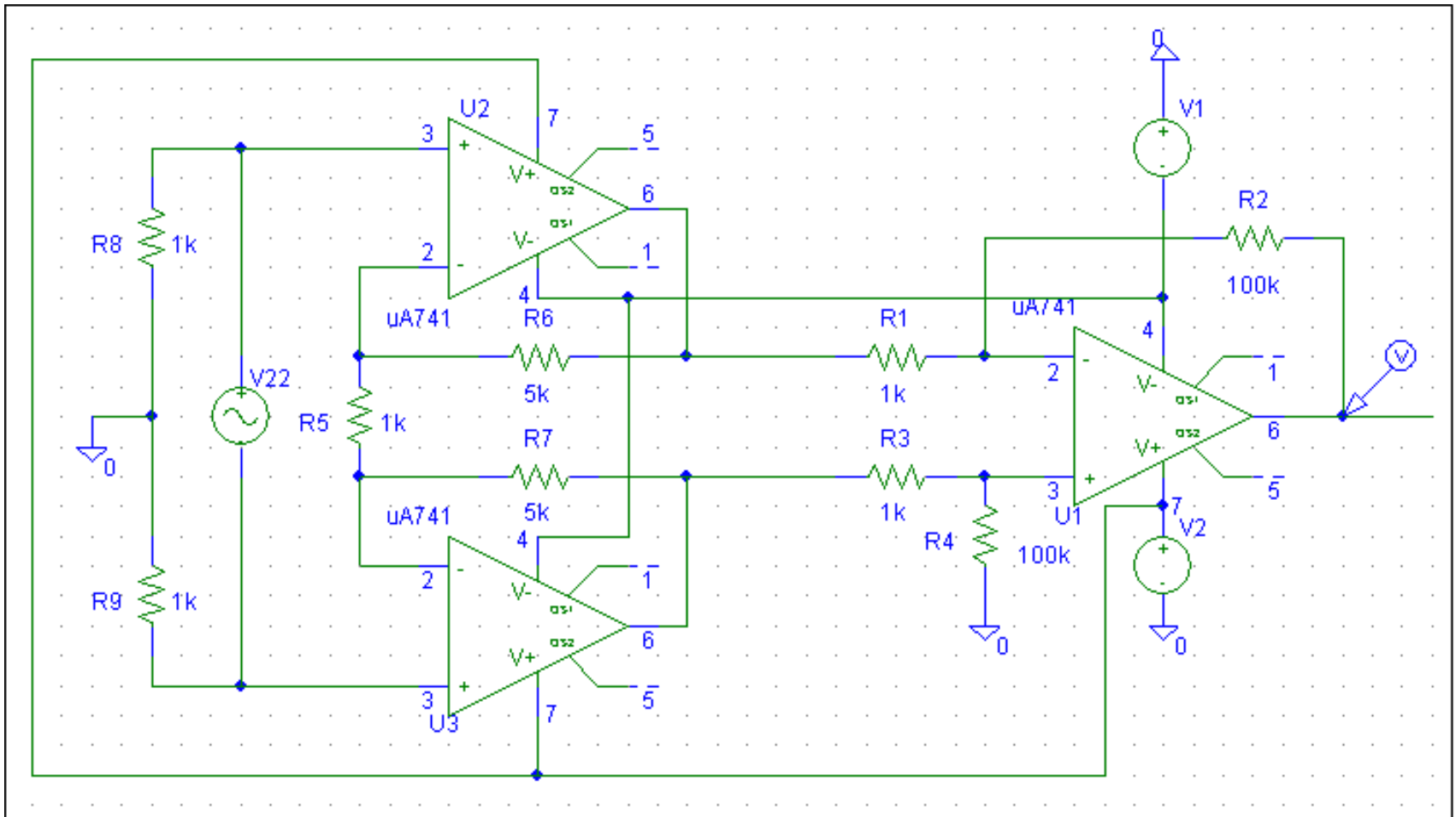


$$\left. \begin{aligned} v_{o1} &= v_{s1} \left(1 + \frac{R_1}{R_2} \right) - v_{s2} \frac{R_1}{R_2} \\ v_{o2} &= v_{s2} \left(1 + \frac{R_1}{R_2} \right) - v_{s1} \frac{R_1}{R_2} \\ v_o &= \frac{R_4}{R_3} (v_{o2} - v_{o1}) \end{aligned} \right\} \Rightarrow A = \frac{v_o}{v_{s2} - v_{s1}} = \left(1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

SIMULARI pentru circuitul de diferenta (2)

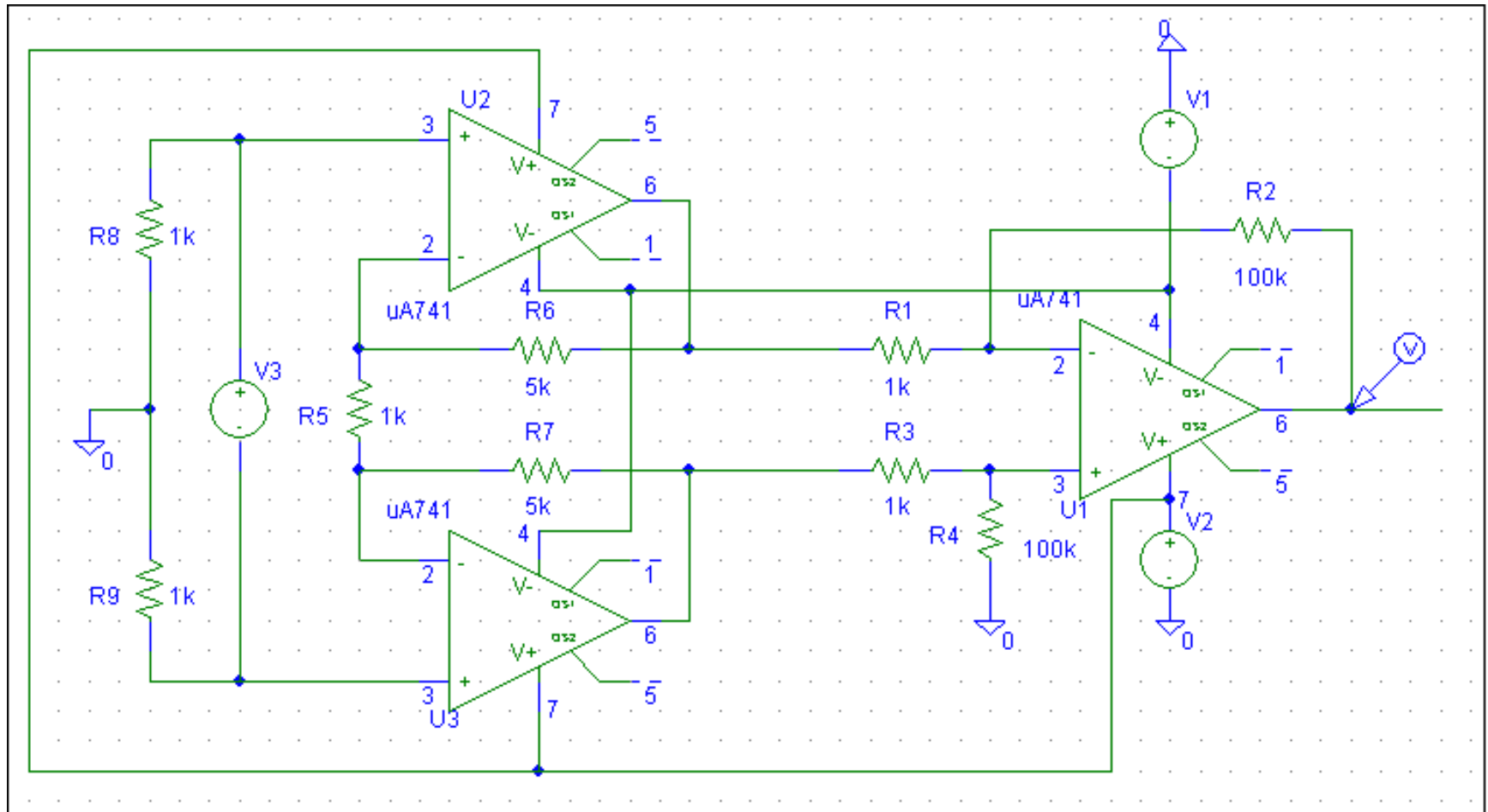
SIMULARI pentru circuitul de diferenta (2)

SIM 2.7: $v_O(t)$

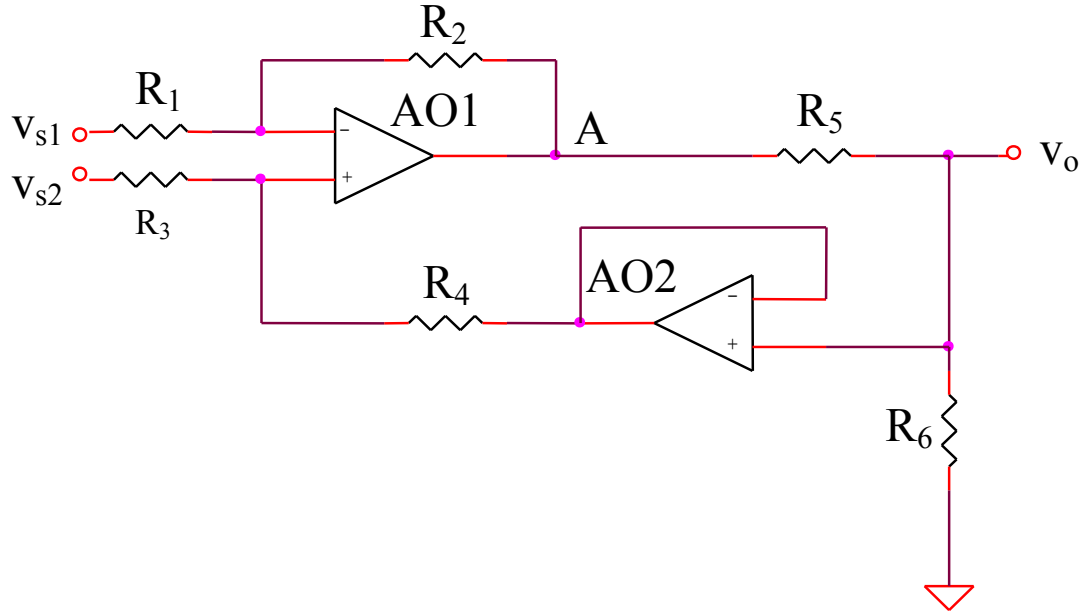


SIMULARI pentru circuitul de diferenta (2)

SIM 2.8: v_O (v_3)



2.2.12. Circuitul de diferenta (3)



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

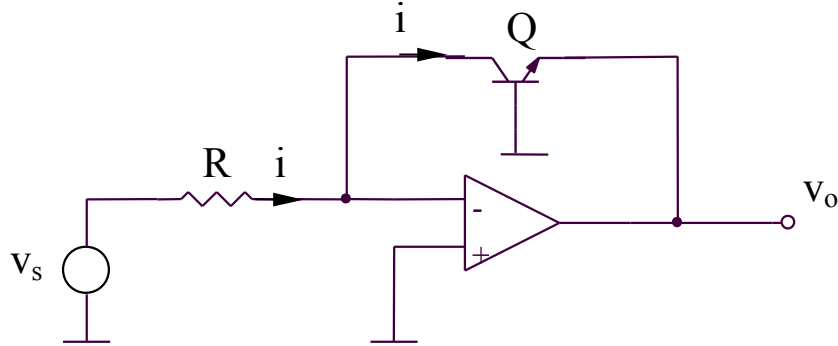
$$v_o = v_A \frac{R_6}{R_5 + R_6}$$

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

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

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

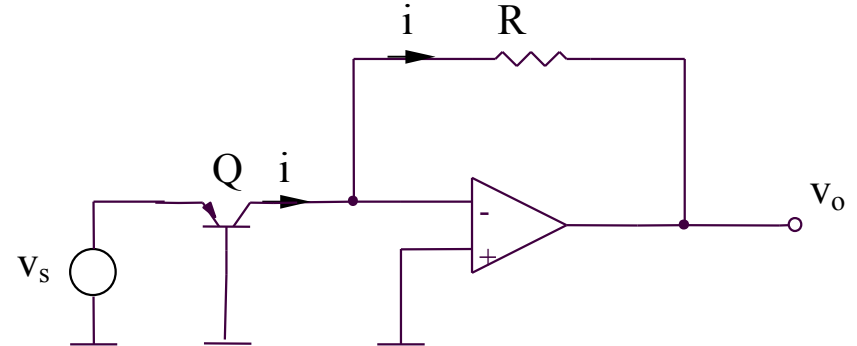
2.2.13. Conversoarele logaritmice si anti-logaritmice



Convertorul logaritmice

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

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



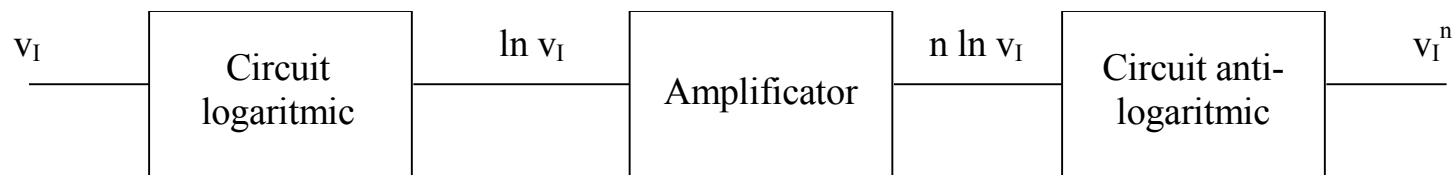
Convertorul anti-logaritmice

$$v_o = -iR$$

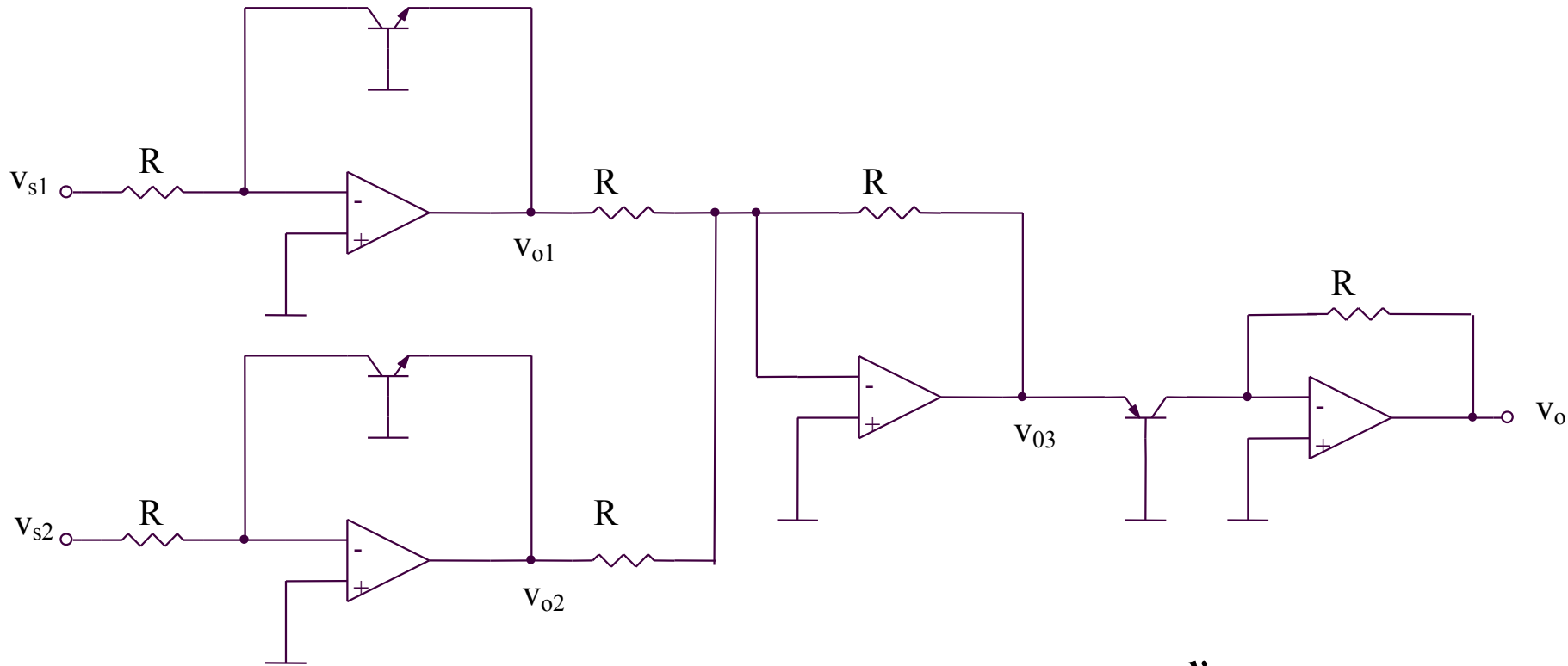
$$i = I_S e^{\frac{v_{EB}}{V_{th}}} = I_S e^{\frac{v_s}{V_{th}}}$$

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

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



2.2.15. Circuit de multiplicare



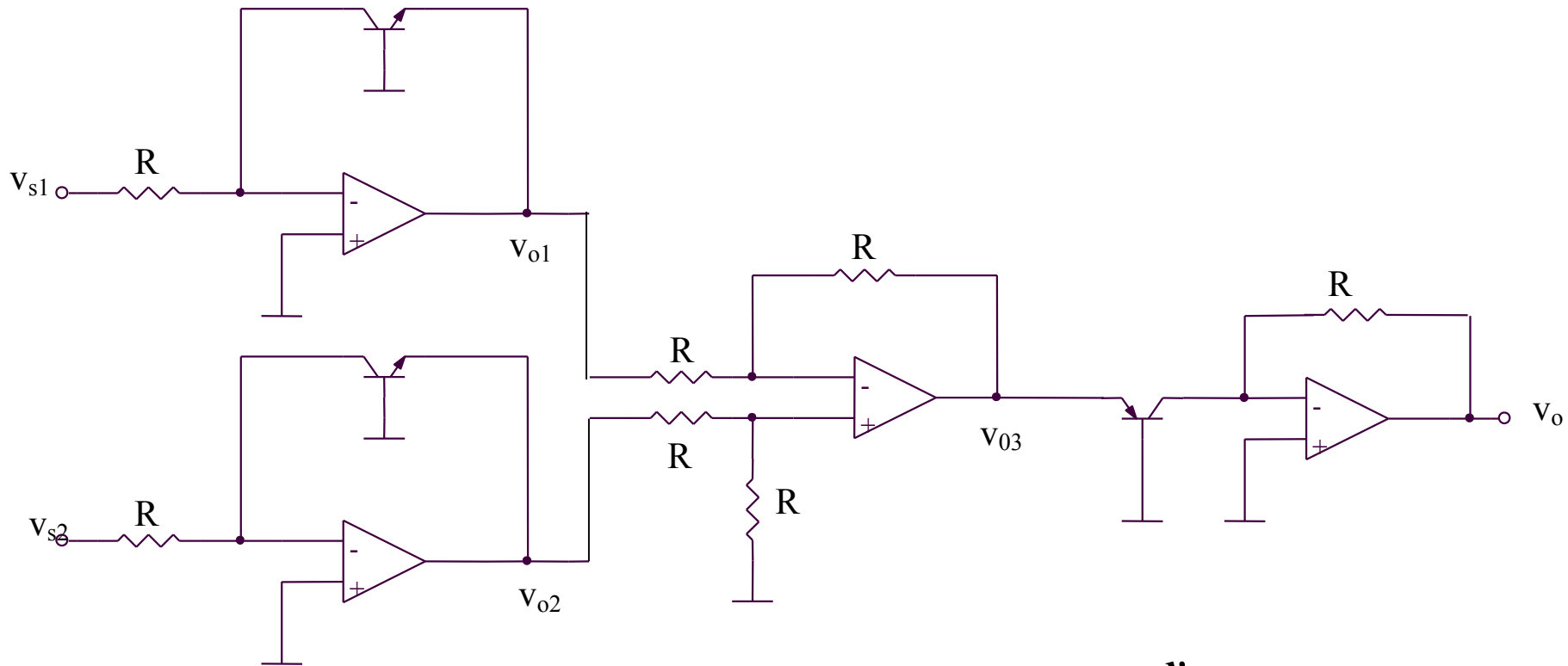
$$v_{o1} = -V_{th} \ln \frac{v_{s1}}{RI_S}$$

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

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

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

2.2.16. Circuit de impartire



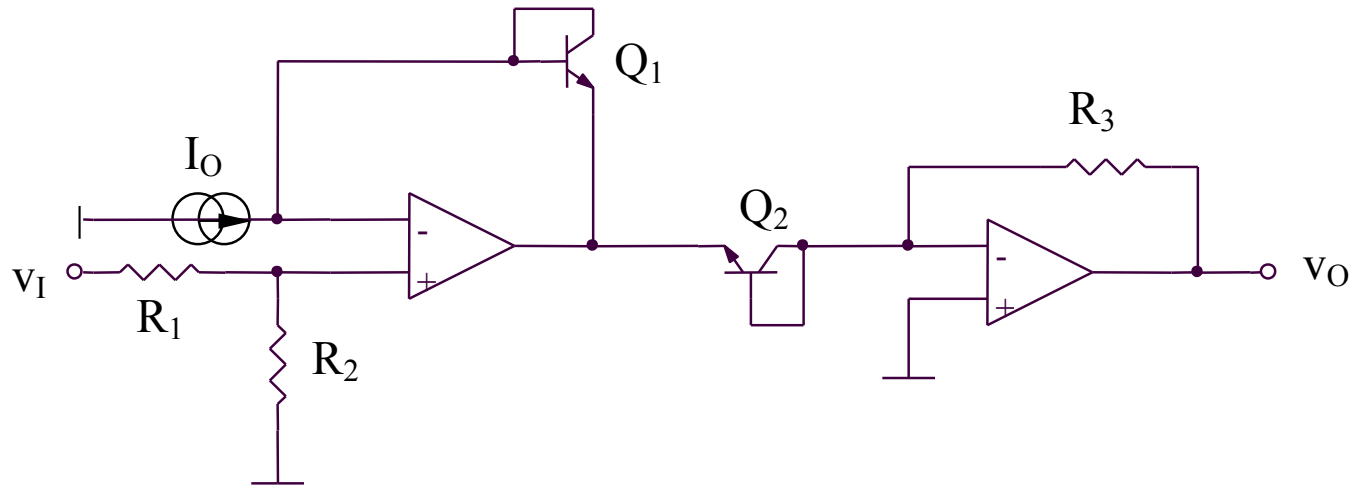
$$v_{o1} = -V_{th} \ln \frac{v_{s1}}{RI_S}$$

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

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

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

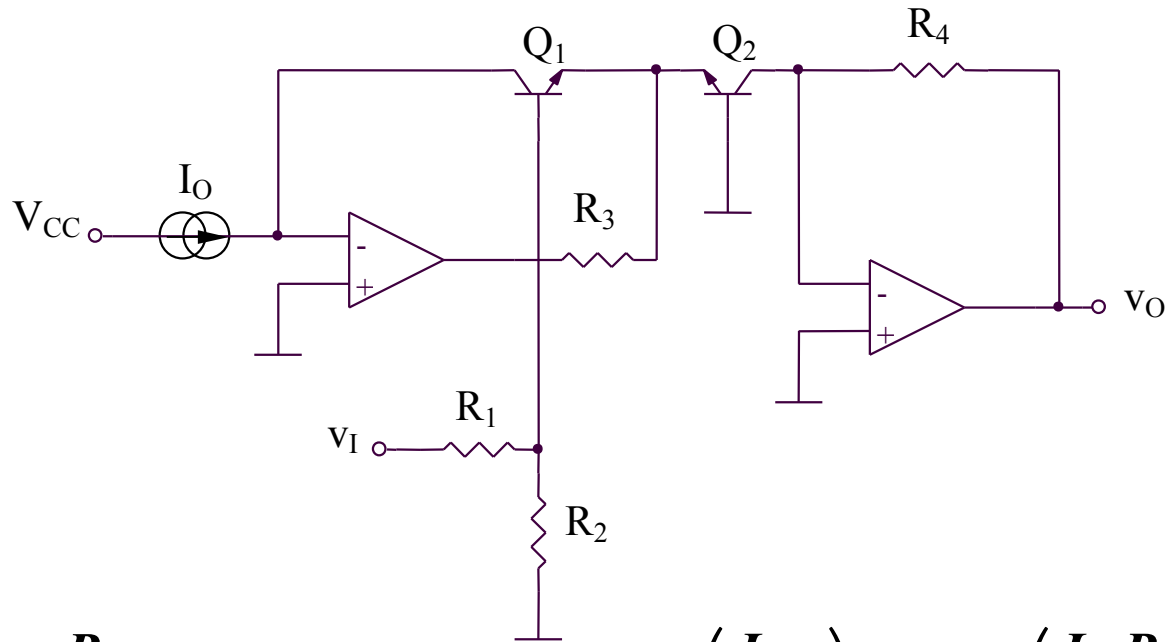
2.2.17. Circuit de exponentiere (1)



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

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

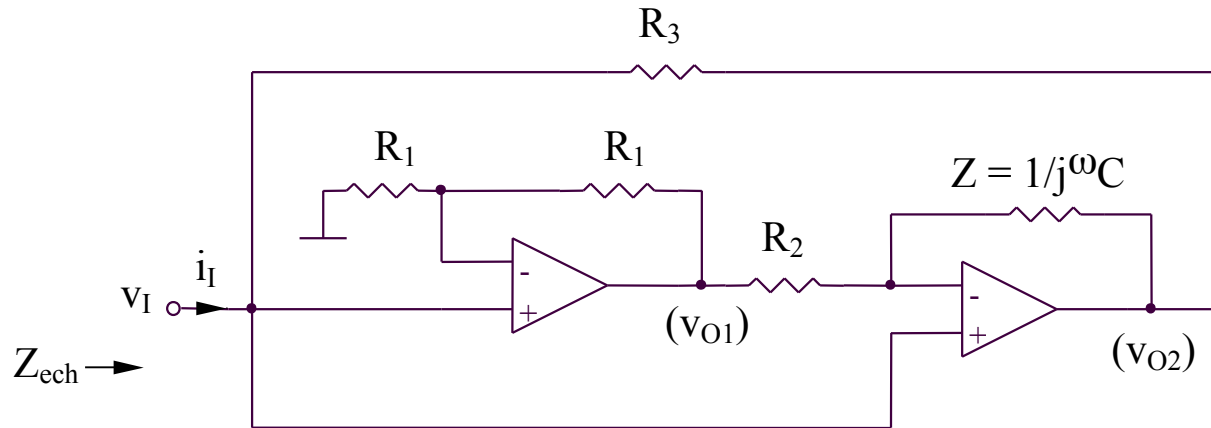
2.2.18. Circuit de exponentiere (2)



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

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

2.2.19. Simulator de impedanta

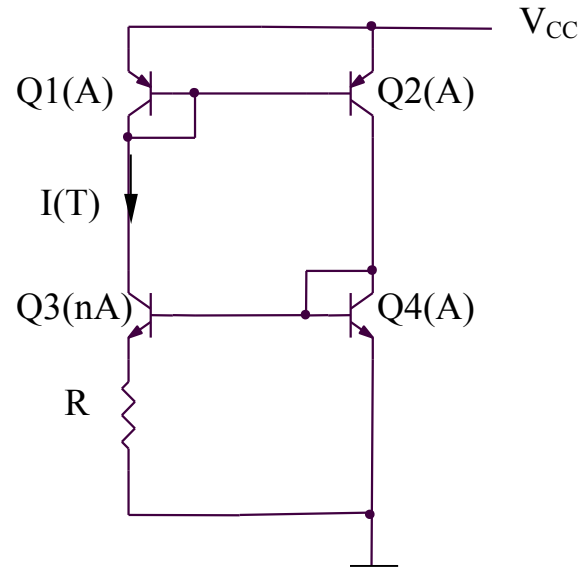


$$\left. \begin{aligned} v_{O2} &= v_I \left(1 + \frac{Z}{R_2} \right) + v_{O1} \left(-\frac{Z}{R_2} \right) \\ v_{O1} &= 2v_I \end{aligned} \right\} \Rightarrow \left. \begin{aligned} v_{O2} &= v_I \left(1 - \frac{Z}{R_2} \right) \\ i_I &= \frac{v_I - v_{O2}}{R_3} \end{aligned} \right\} \Rightarrow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

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

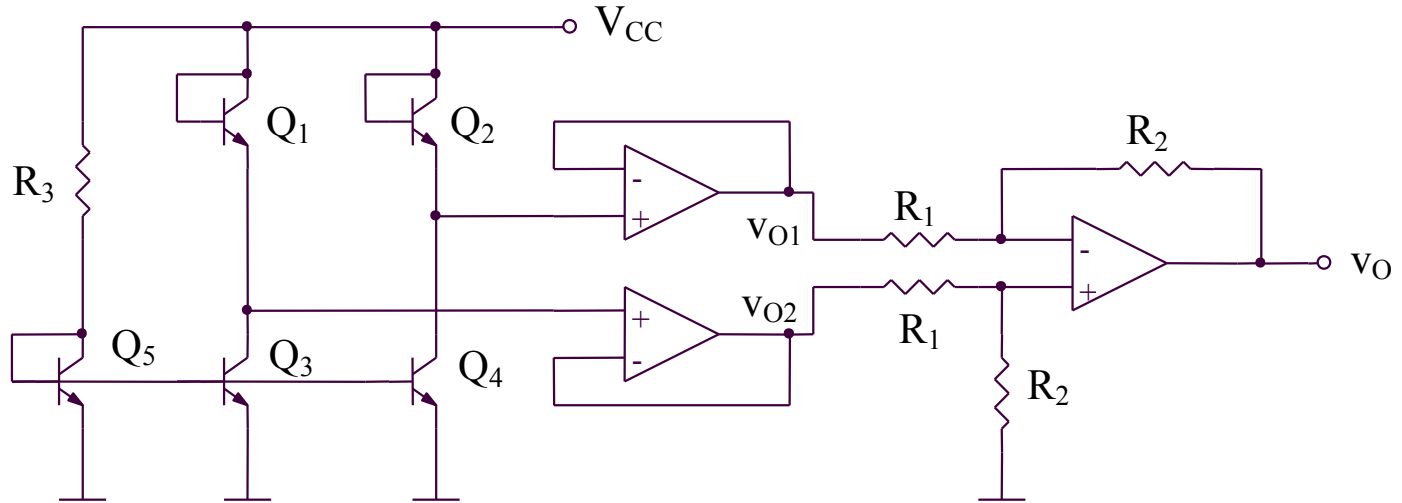
$$L_{ech} = R_2 R_3 C$$

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)

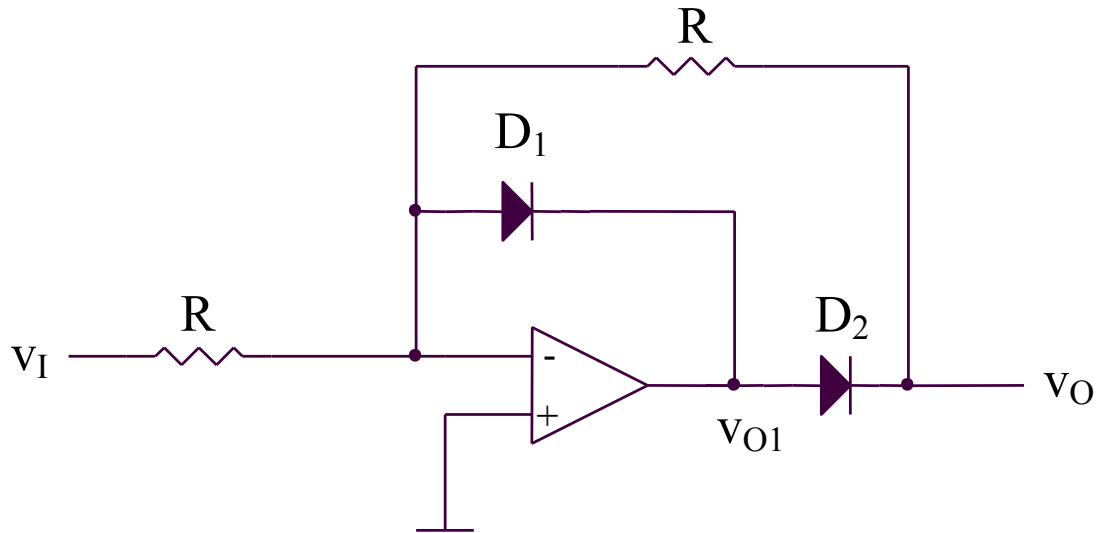


$$v_O = \frac{R_2}{R_1} (v_{O2} - v_{O1}) = \frac{R_2}{R_1} (v_{BE2} - v_{BE1}) = \frac{R_2}{R_1} V_{th} \ln \left(\frac{I_{C2} I_{S1}}{I_{C1} I_{S2}} \right) \Rightarrow$$

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

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

2.2.22. Redresor mono-alternanta

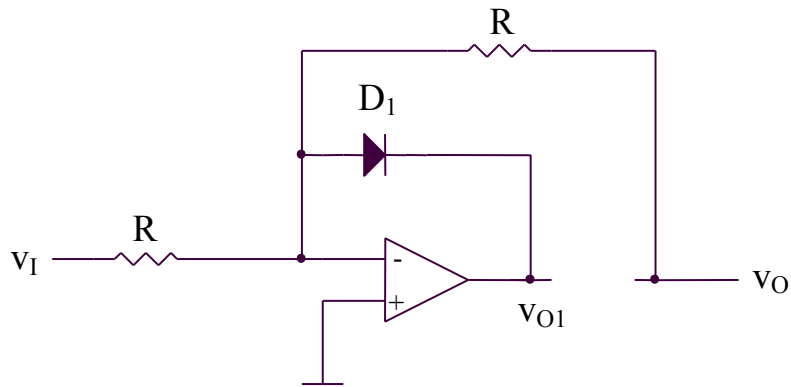


$v_I > 0 \Rightarrow v_{O1} < 0 \Rightarrow D_1$ deschisa, D_2 blocata

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

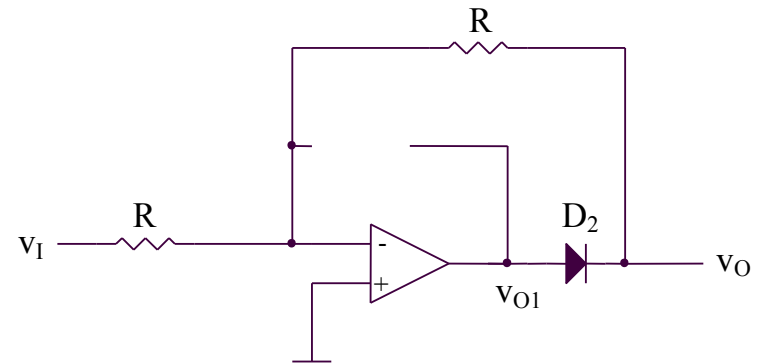
2.2.22. Redresor mono-alternanta

$$v_I > 0$$



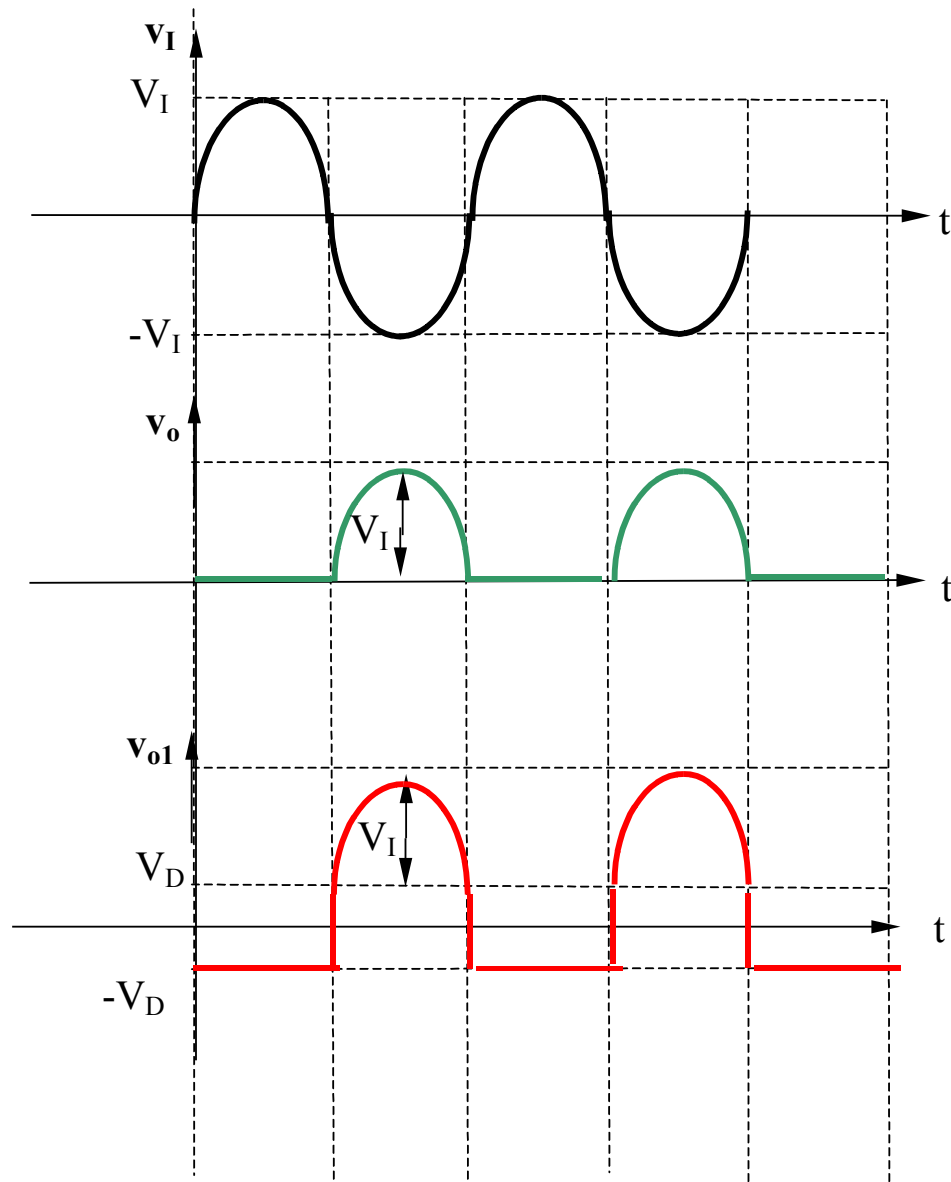
$$v_O = 0$$

$$v_I < 0$$



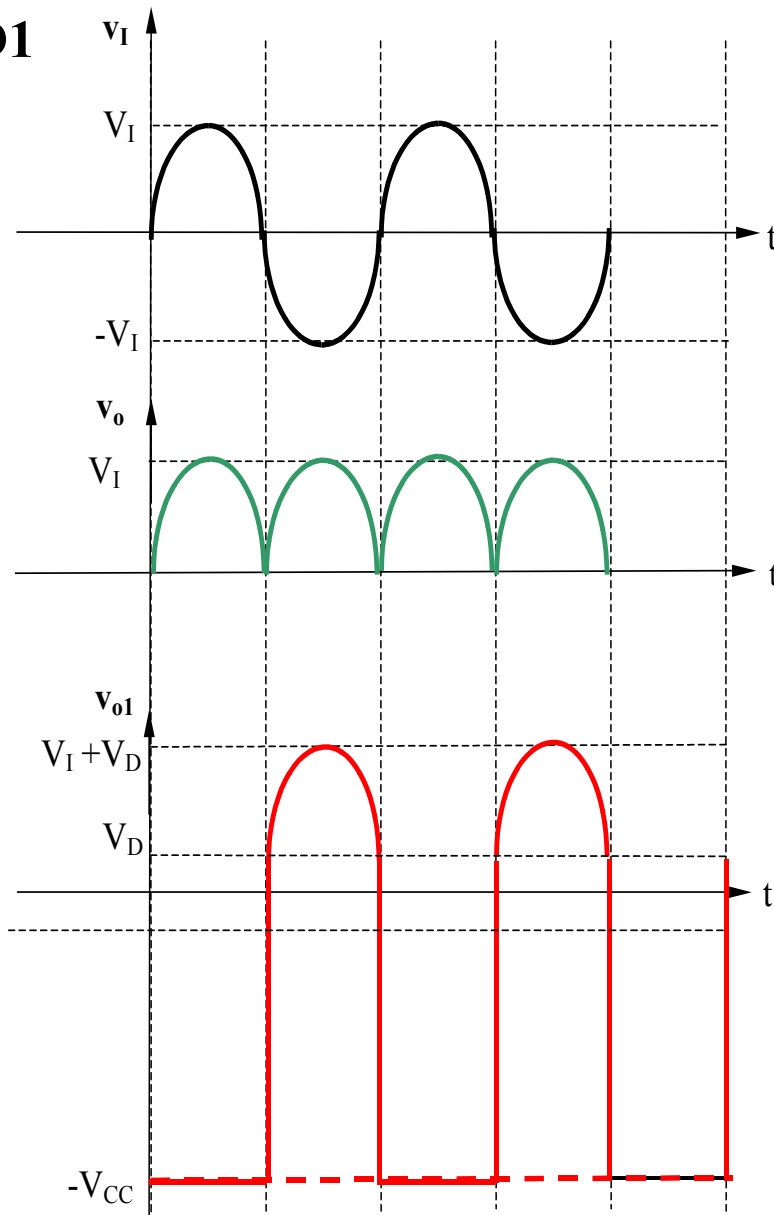
$$v_O = -\frac{R}{R}v_I = -v_I$$

2.2.22. Redresor mono-alternanta



2.2.22. Redresor mono-alternanta

Fara D1



Exemplu

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

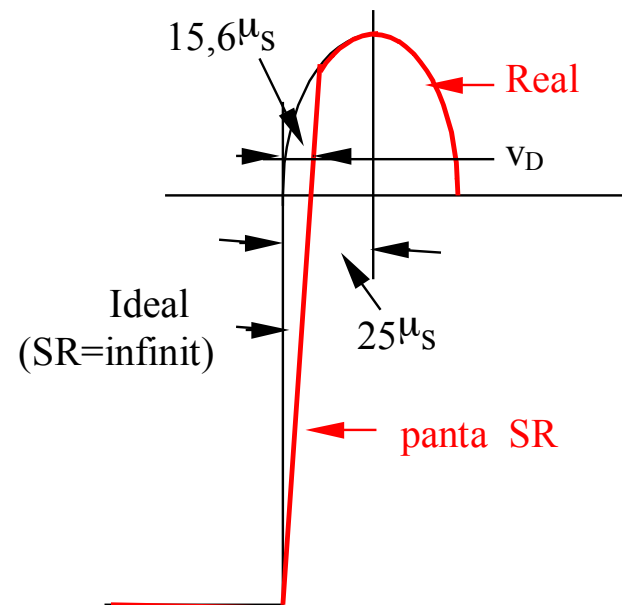
$$T=1/f=100\ \mu\text{s}$$

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

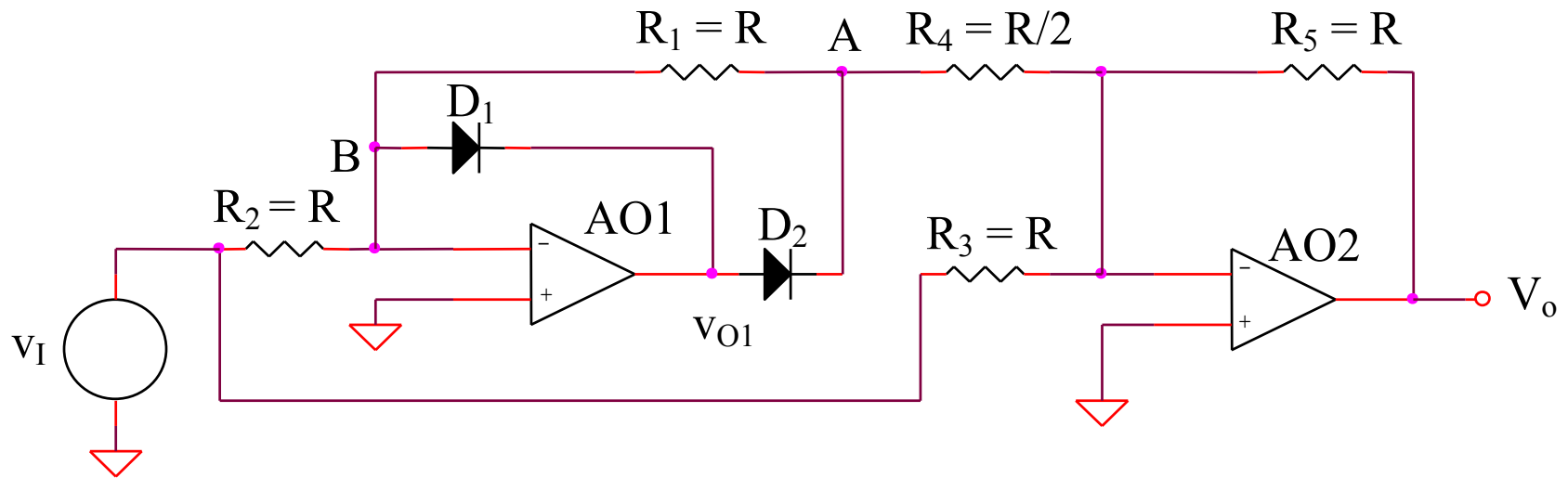
$$SR=1\text{V}/\mu\text{s}$$

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

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



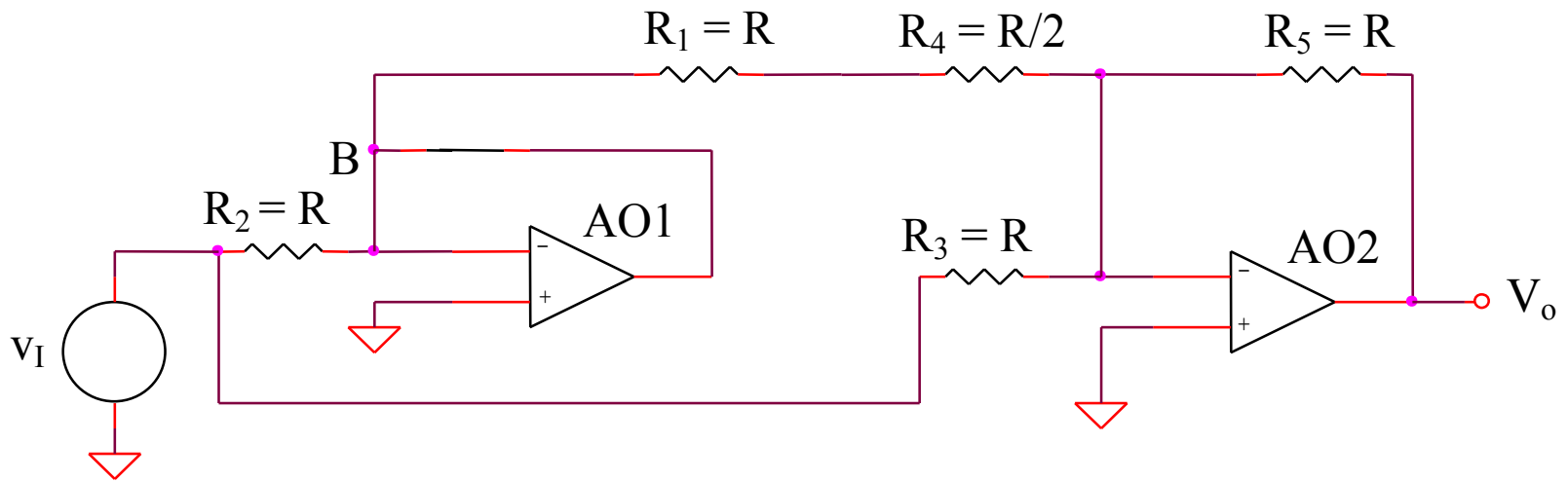
2.2.23. Redresor bi-alternanta (1)



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

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

2.2.23. Redresor bi-alternanta (1)

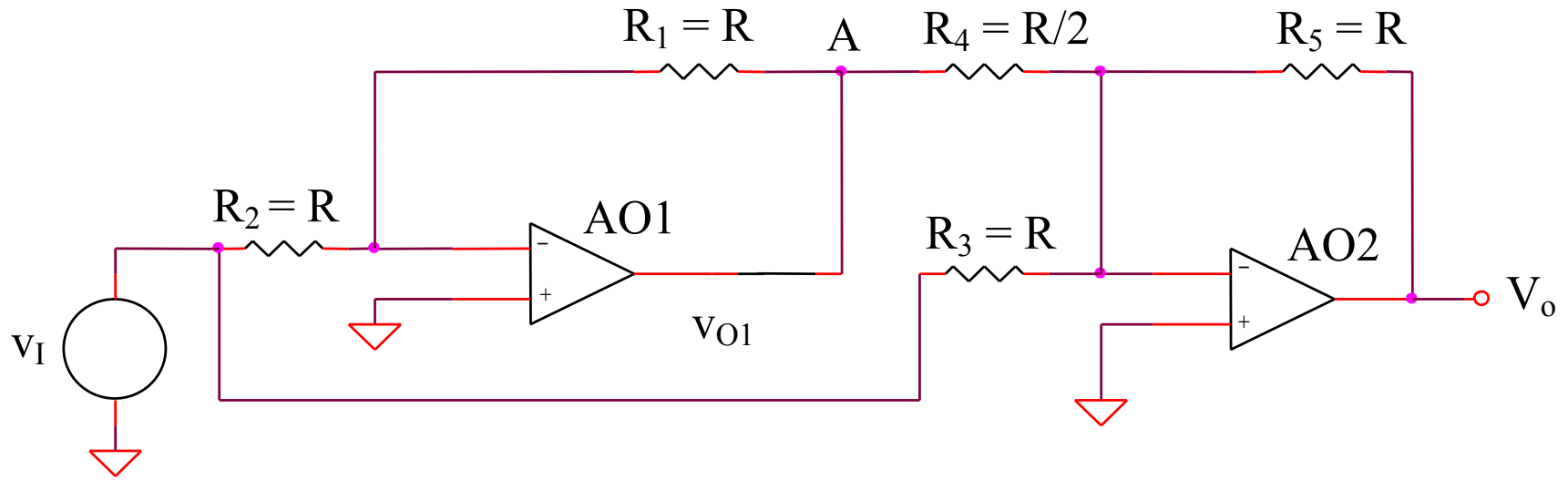


$$v_I > 0$$

$$V_B = 0$$

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

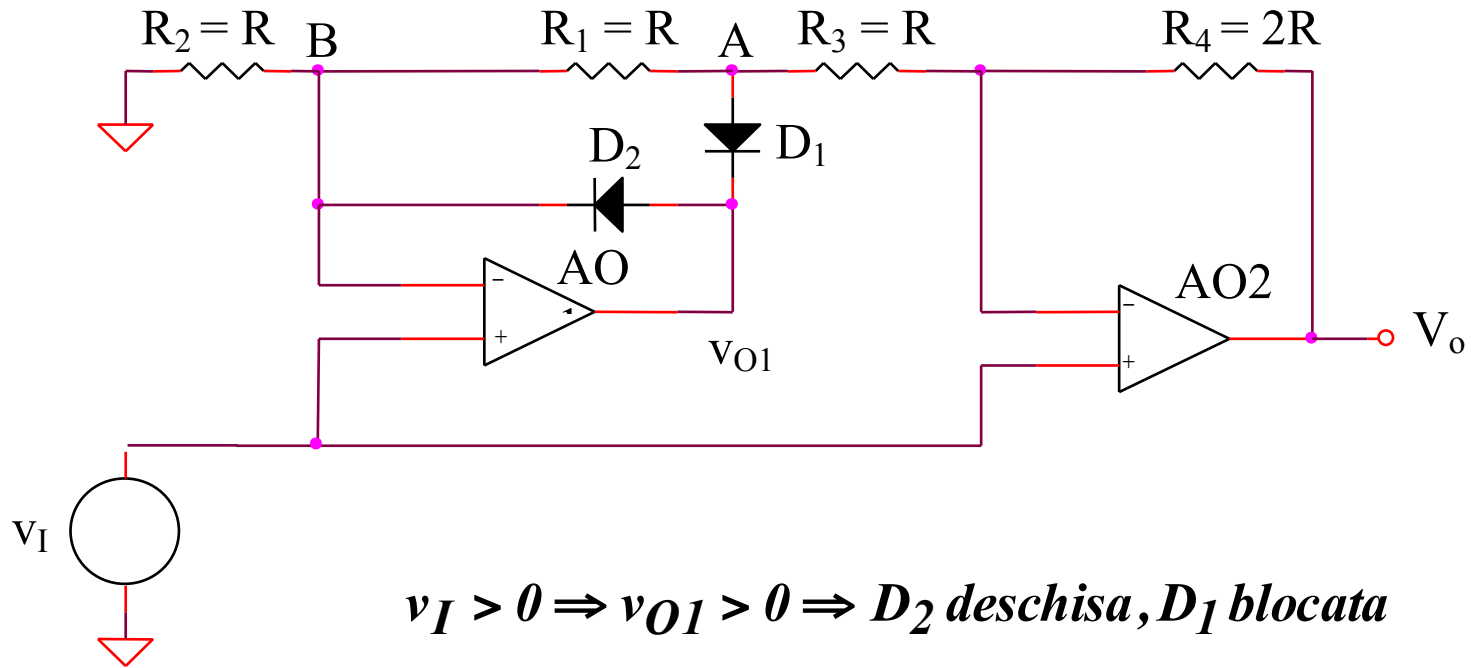
2.2.23. Redresor bi-alternanta (1)



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

Concluzie: $v_O = -|v_I|$

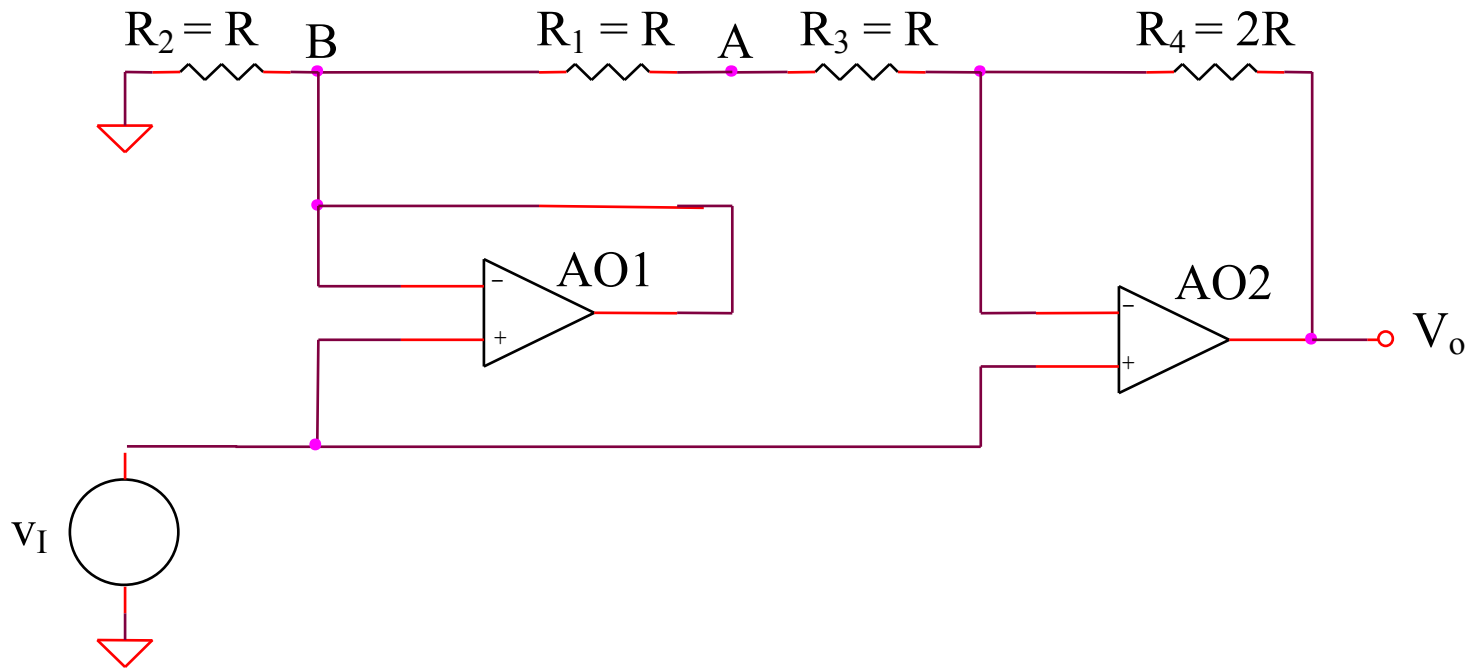
2.2.24. Redresor bi-alternanta (2)



$v_I > 0 \Rightarrow v_{O1} > 0 \Rightarrow D_2$ 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)

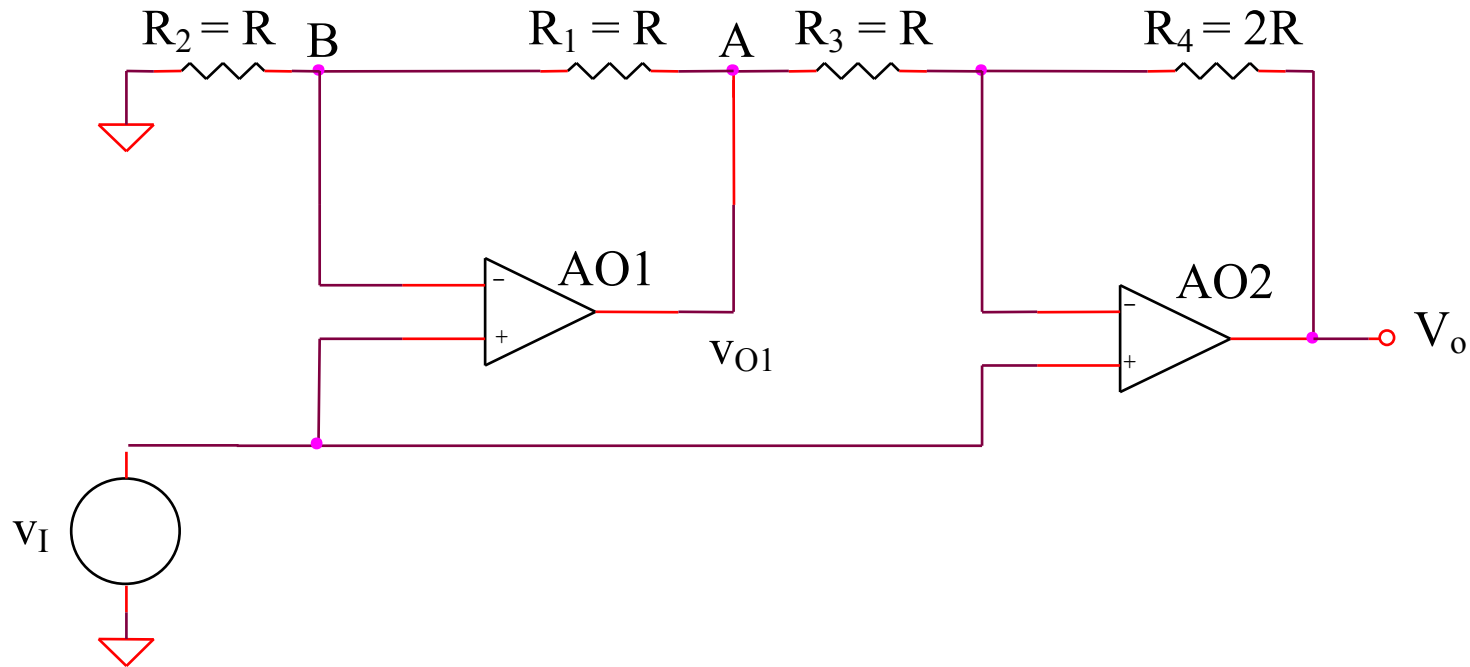


$$v_I > 0$$

$$V_B = v_I$$

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

2.2.24. Redresor bi-alternanta (2)



$$v_I < 0$$

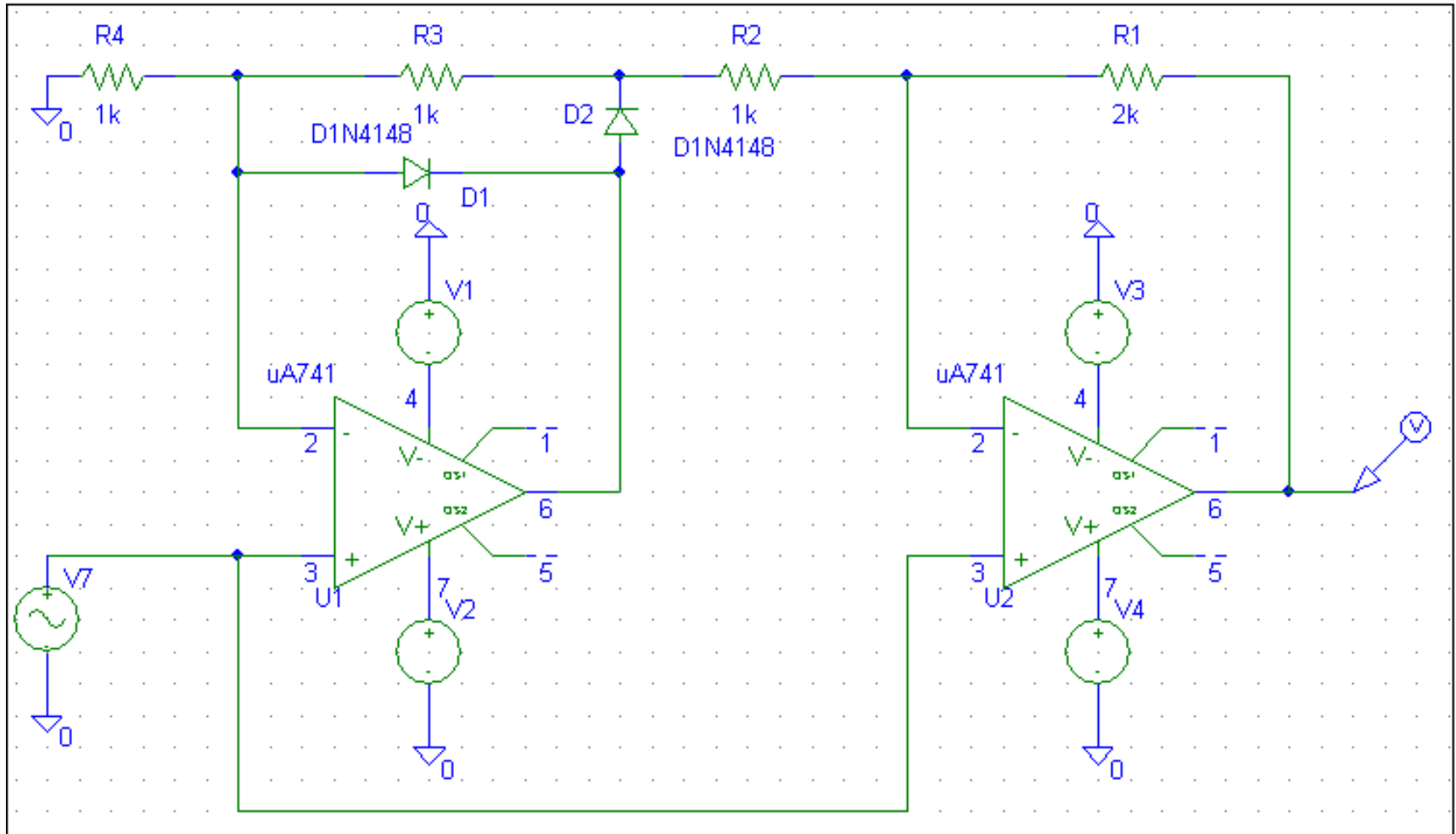
$$V_A = \left(1 + \frac{R_1}{R_2}\right)v_I = 2v_I \quad v_O = \left(1 + \frac{R_4}{R_3}\right)v_I - \frac{R_4}{R_3}V_A = -v_I$$

Concluzie: $v_O = |v_I|$

SIMULARI pentru redresorul bialternanta (2)

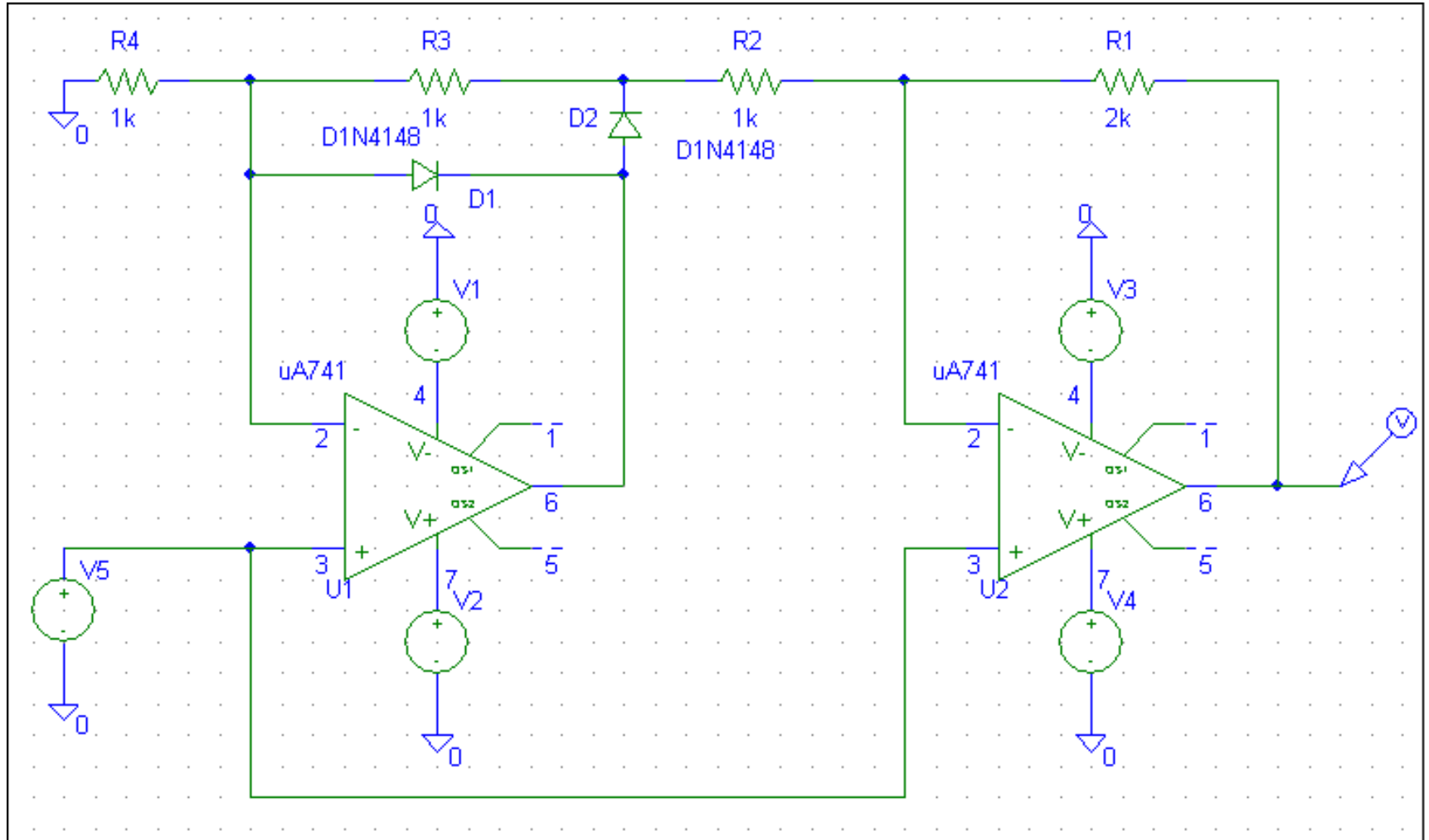
SIMULARI pentru redresorul bialternanta (2)

SIM 2.9: $v_O(t)$

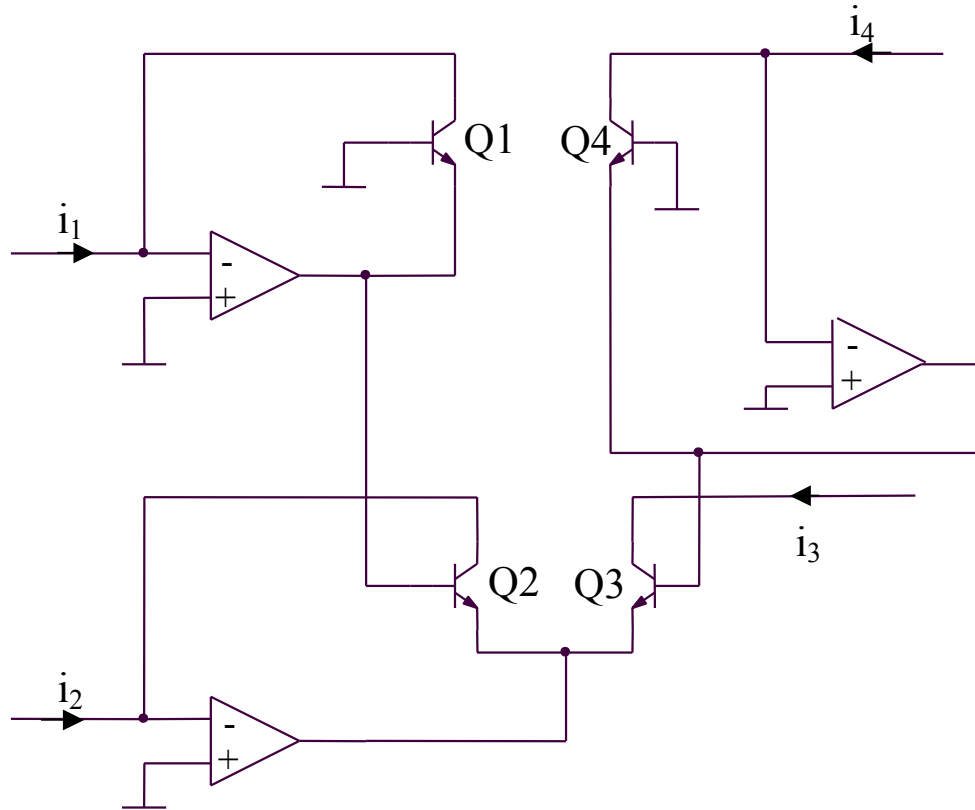


SIMULARI pentru redresorul bialternanta (2)

SIM 2.10: v_O (v_5)



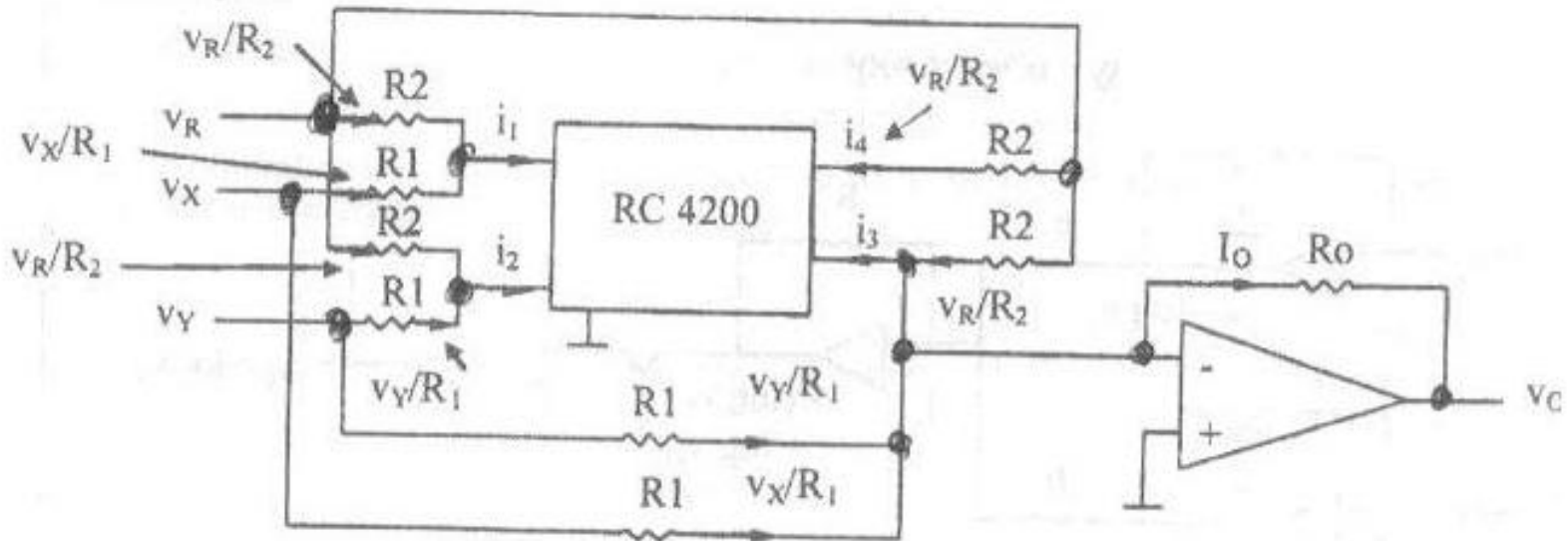
2.2.25. Circuit multifunctional RC 4200



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

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

2.2.25. Circuit multifunctional RC 4200 - aplicatie

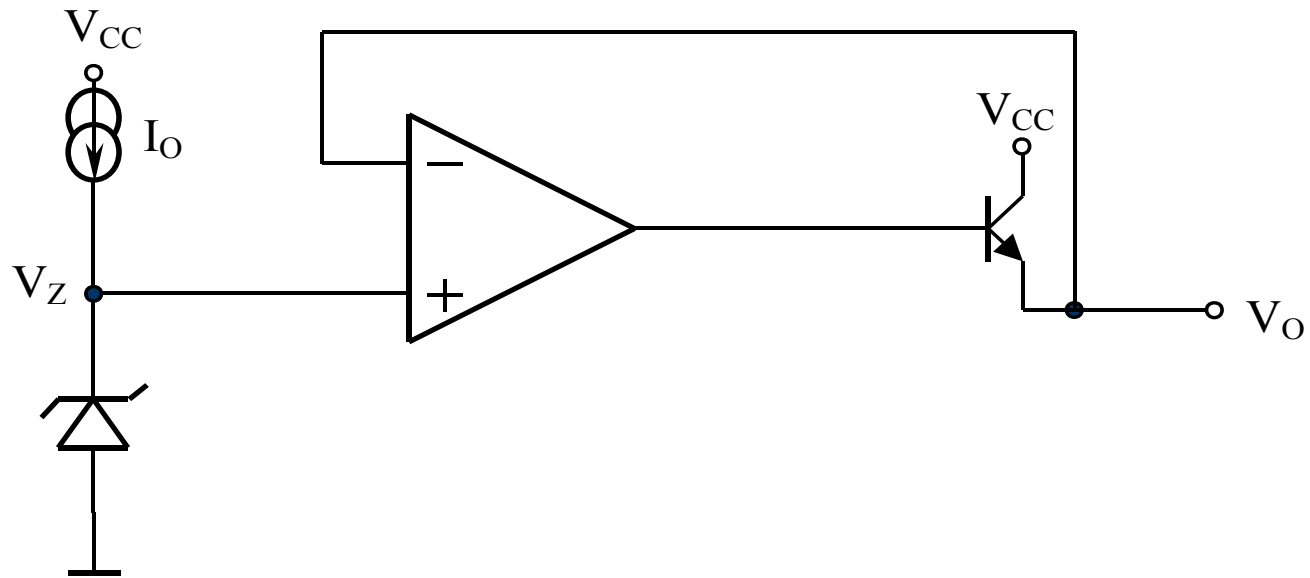


$$i_3 = \frac{i_1 i_2}{i_4} = \frac{R_2 \left(\frac{V_R}{R_2} + \frac{V_X}{R_1} \right) \left(\frac{V_R}{R_2} + \frac{V_Y}{R_1} \right)}{V_R \left(\frac{R_2}{R_2} + \frac{R_1}{R_1} \right)} = \frac{V_R}{R_2} + \frac{V_X}{R_1} + \frac{V_Y}{R_1} + \frac{R_2 V_X V_Y}{V_R R_1^2}$$

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

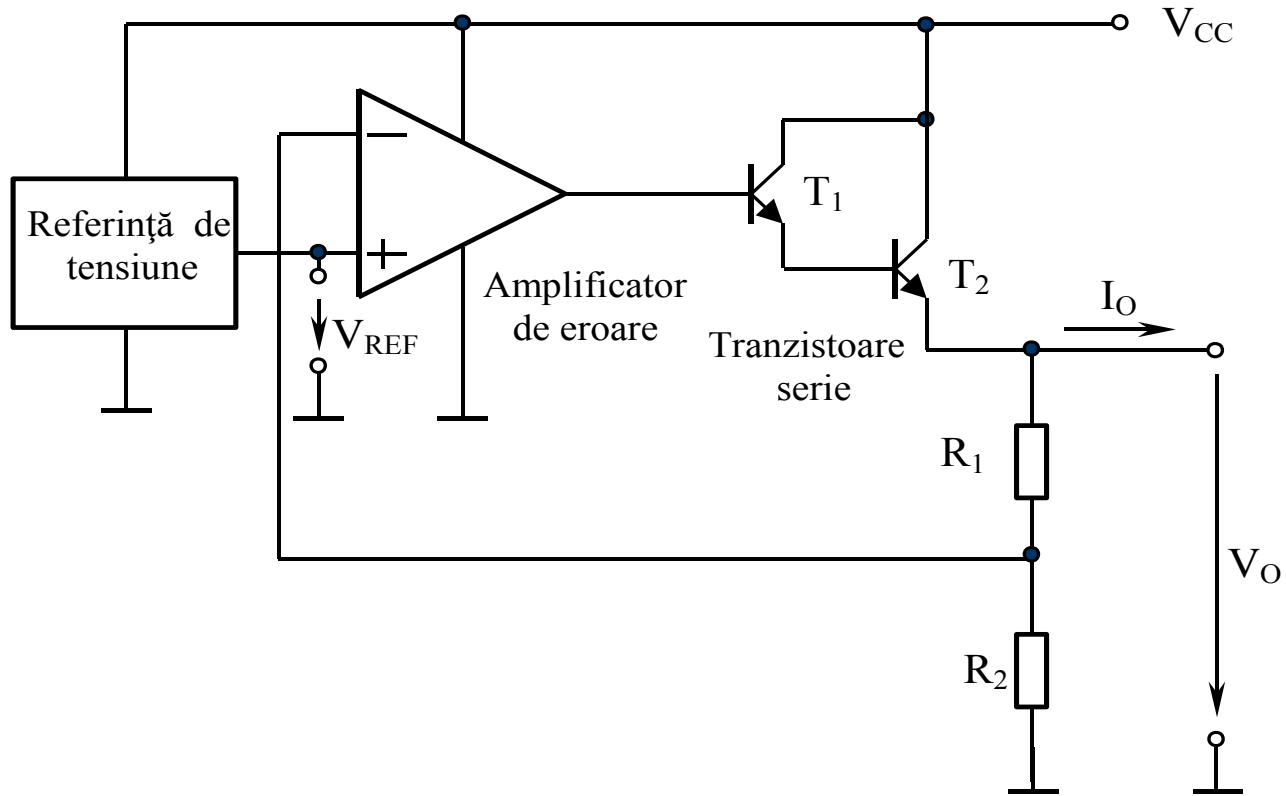
$$v_O = -i_O R_0 = \frac{R_2 R_0}{V_R R_1^2} V_X V_Y$$

2.2.26. Stabilizator de tensiune (1)



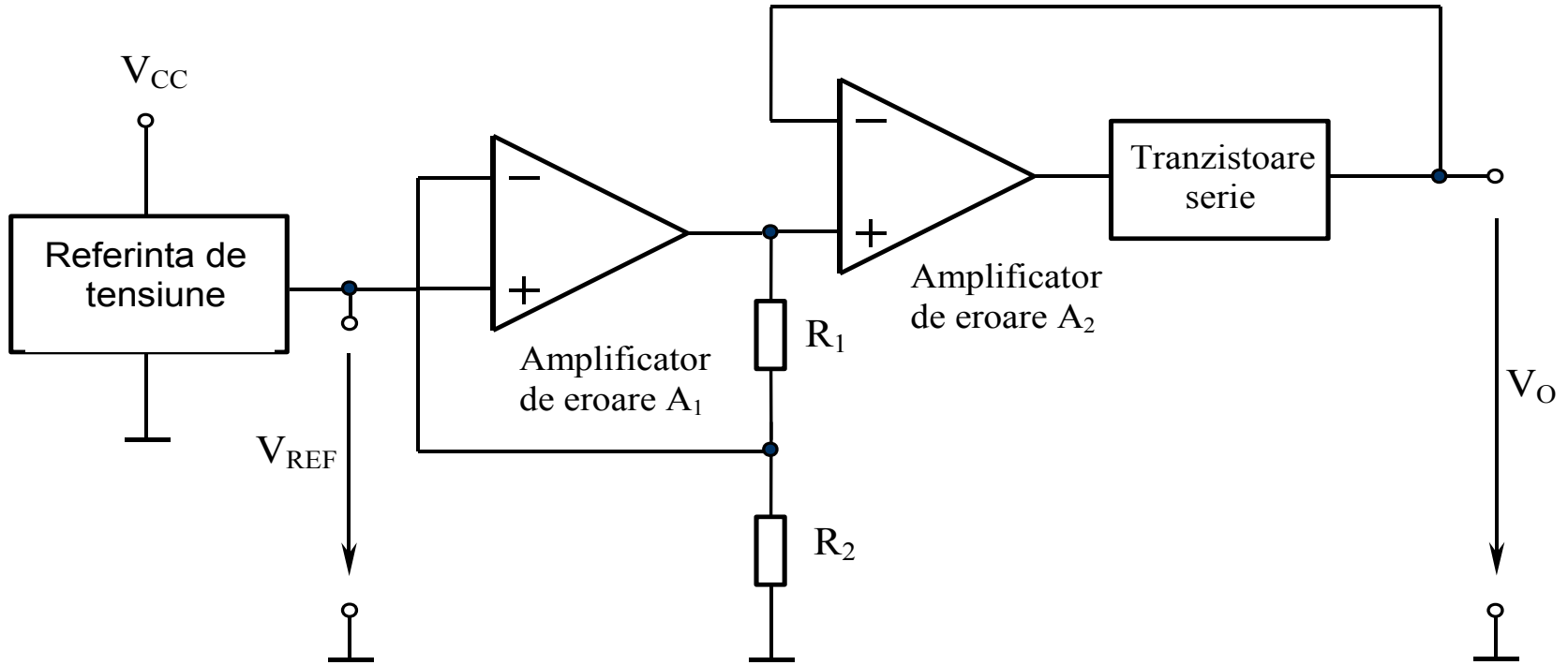
$$V_O = V_Z$$

2.2.27. Stabilizator de tensiune (2)



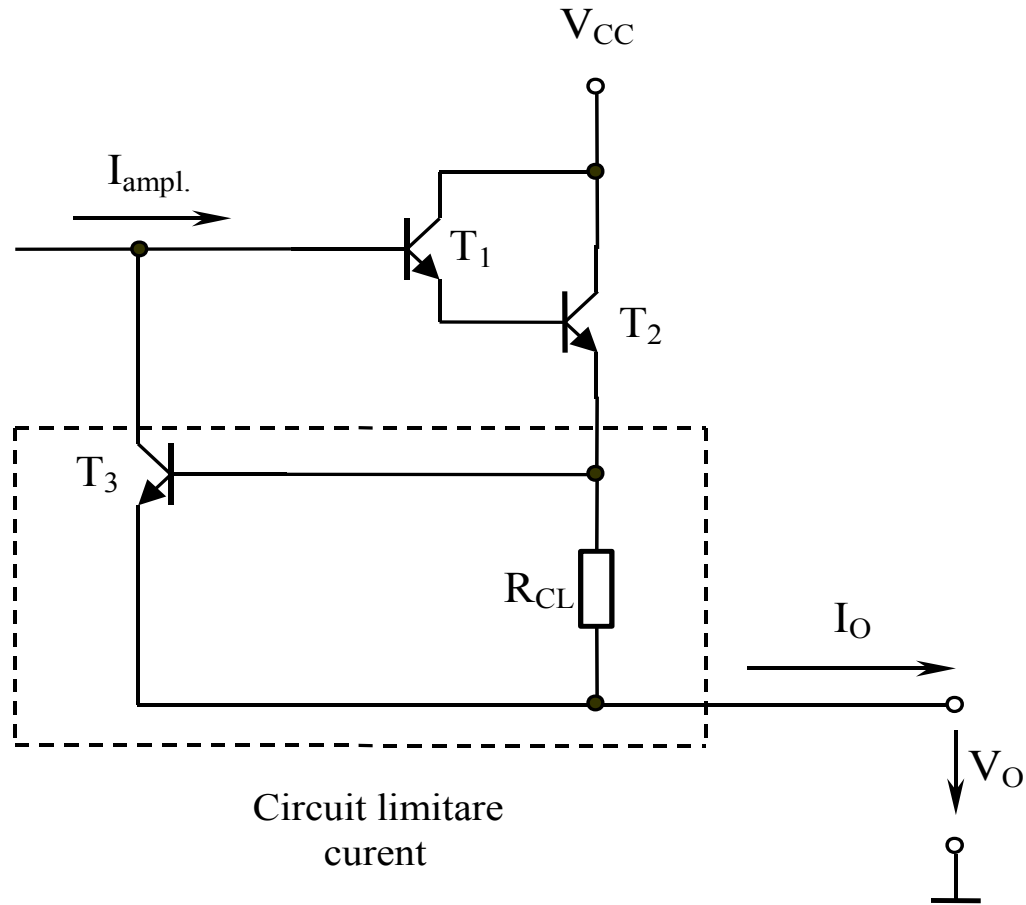
$$V_O \frac{R_2}{R_1 + R_2} = V_{REF} \Rightarrow V_O = V_{REF} \left(1 + \frac{R_1}{R_2} \right)$$

2.2.28. Stabilizator de tensiune (3)



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

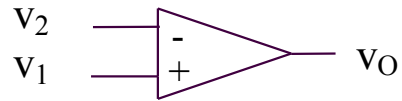
2.2.29. Circuit de protectie la supracurent



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

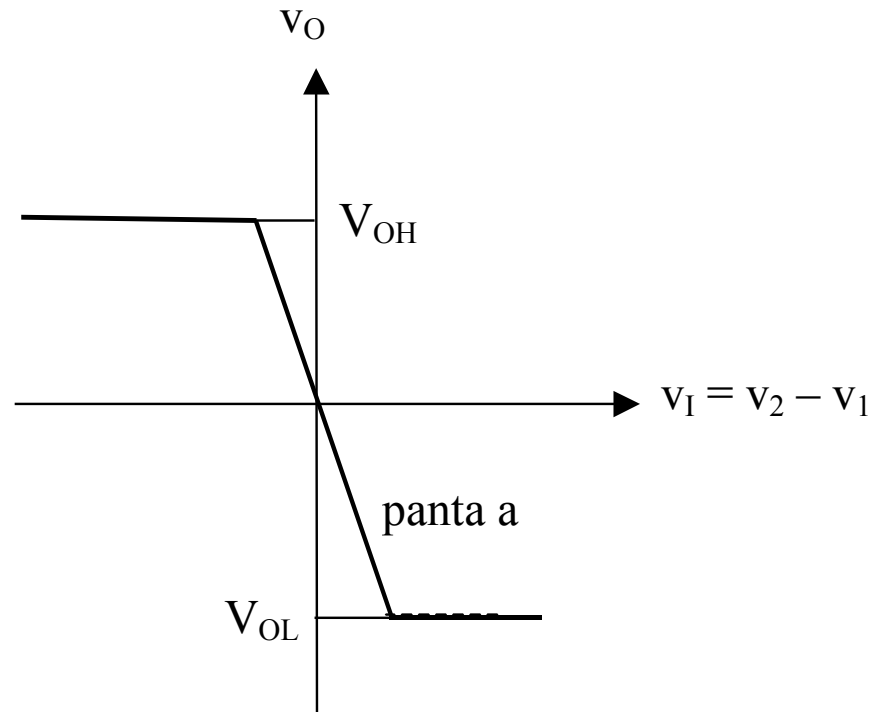
2.3. Comparatoare

2.3.1. Comparator semplu

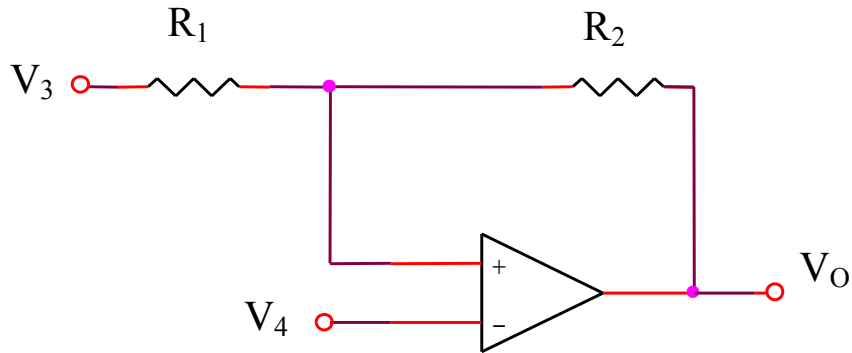


$$v_1 > v_2 \Rightarrow v_O = V_{OH}$$

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



2.3.2. Comparator cu histerezis

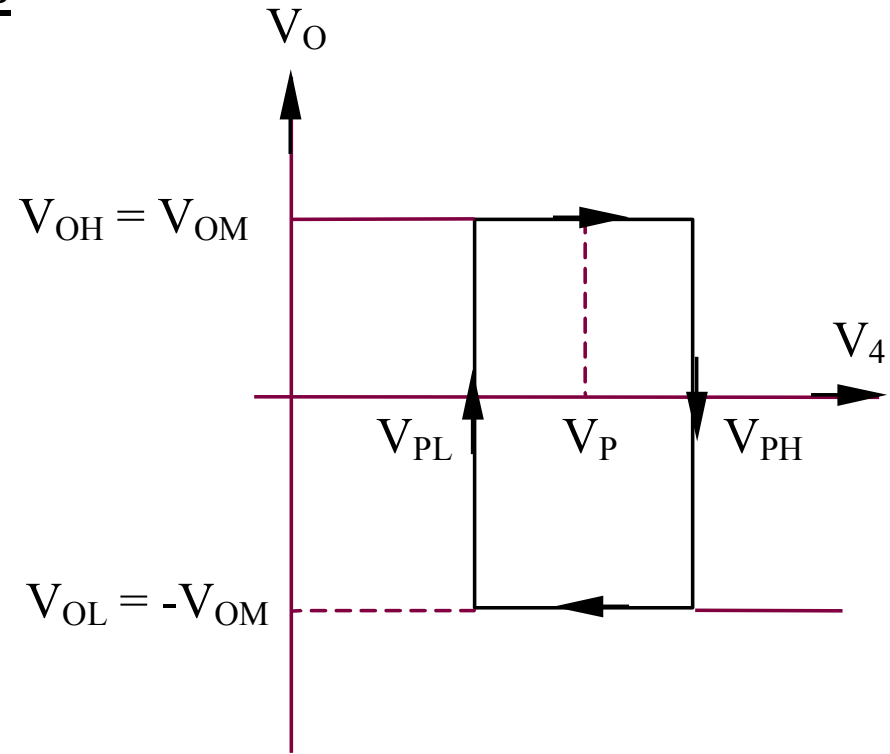


V_3 – sursa de tensiune constanta

V_4 – sursa de tensiune variabila

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

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



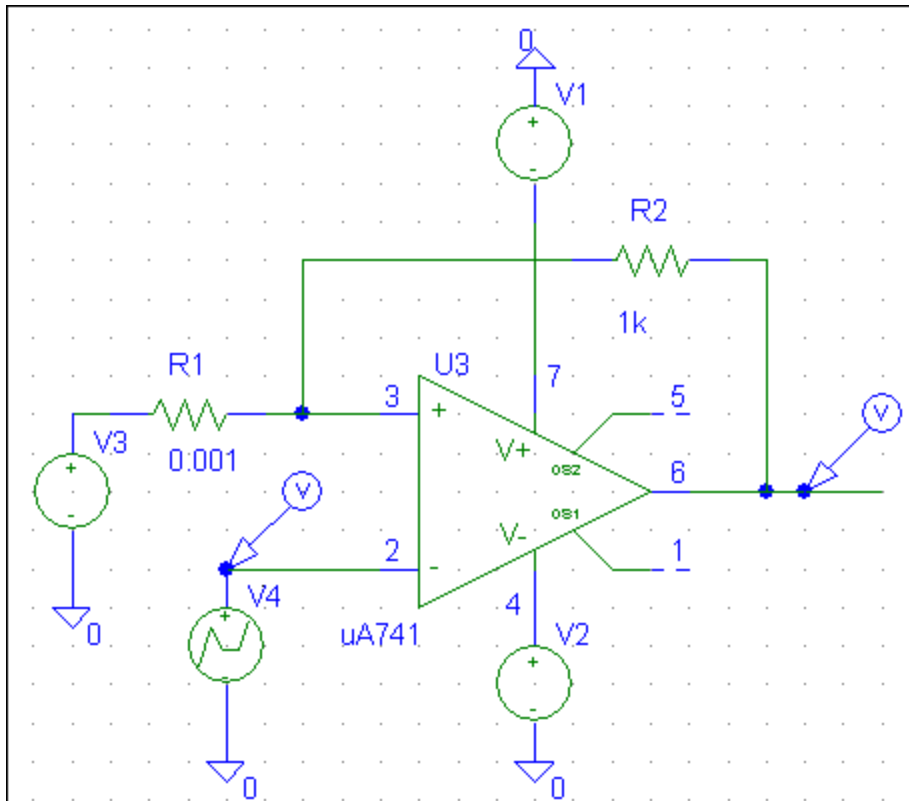
$$V_{PH} = V_3 \frac{R_2}{R_1 + R_2} + V_{OH} \frac{R_1}{R_1 + R_2}$$

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

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

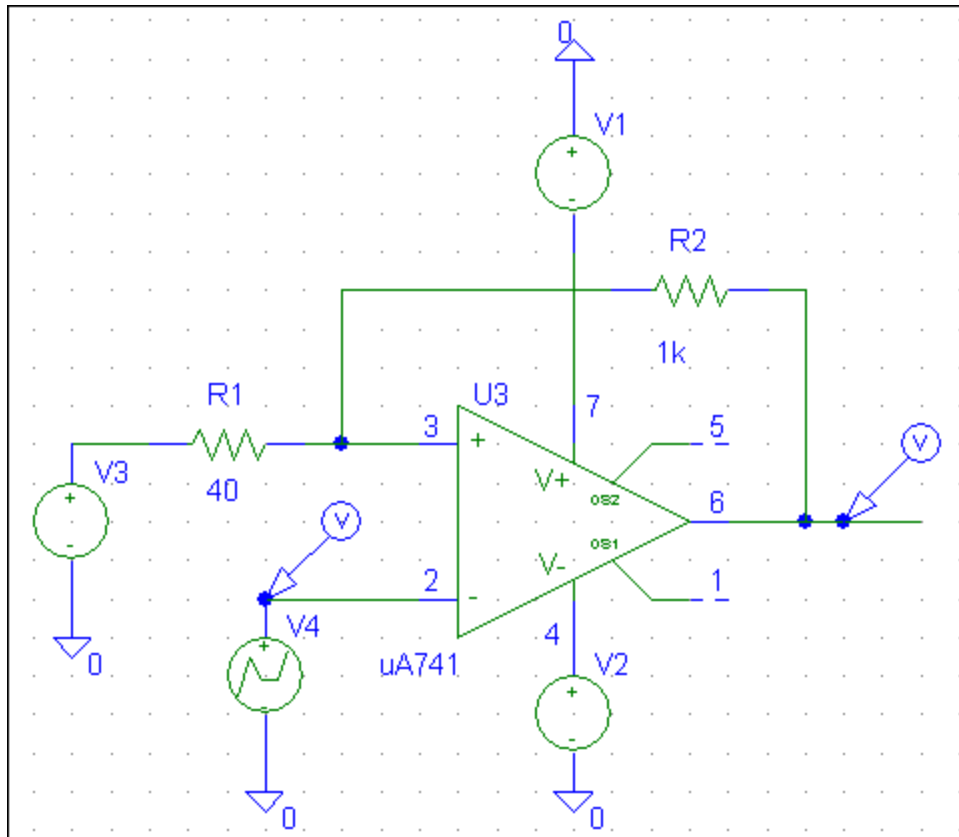
$$V_{OM} \cong 8,5V$$

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

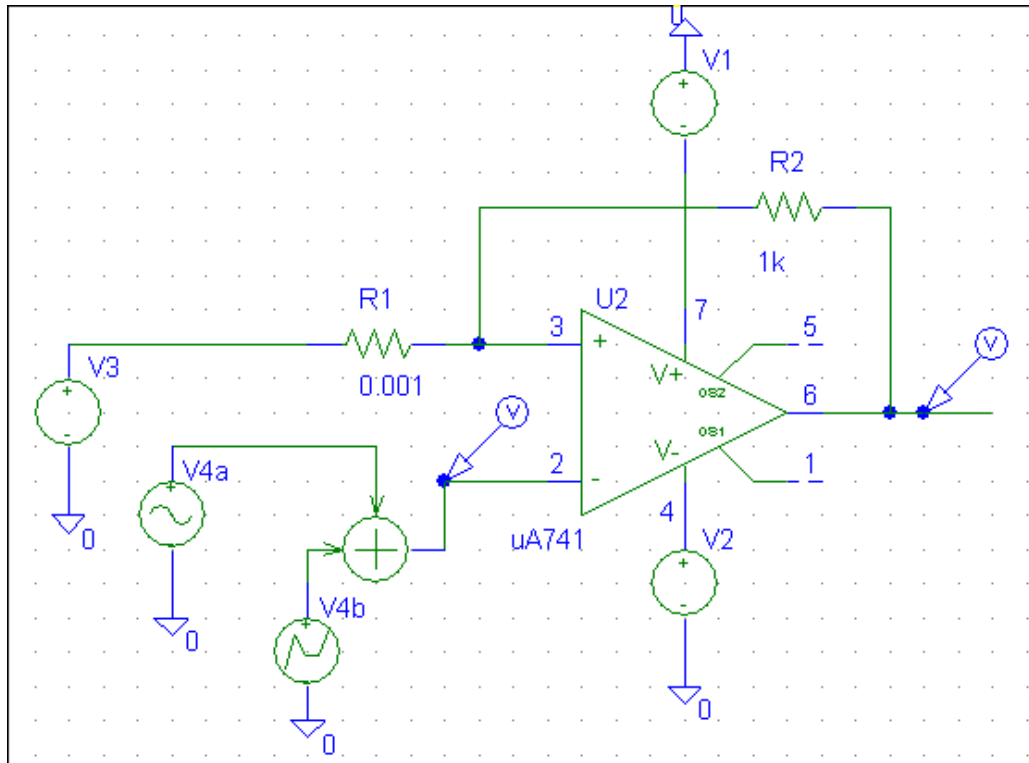
$$V_{OM} \cong 8,5V$$

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

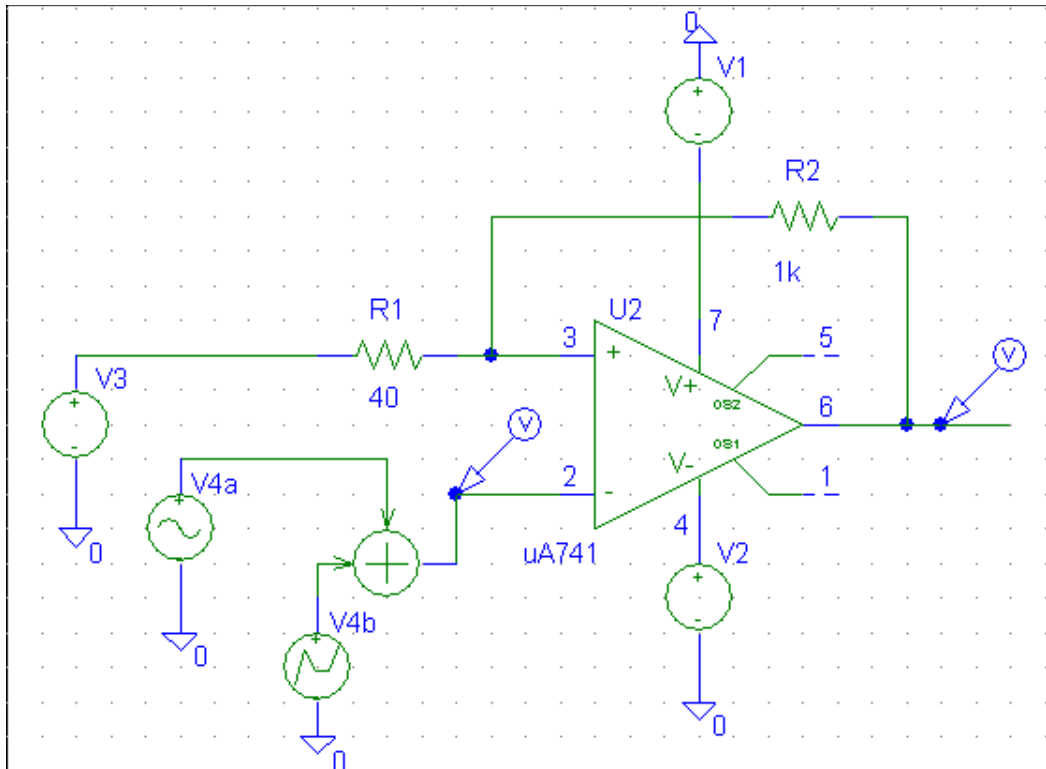
$$V_{OM} \cong 8,5V$$

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

$$a > 10^5$$

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

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

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

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

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

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

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

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

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

$$R_O = 75\Omega$$

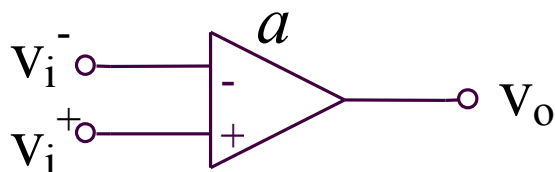
$$f_U = 1\text{MHz}$$

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

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:

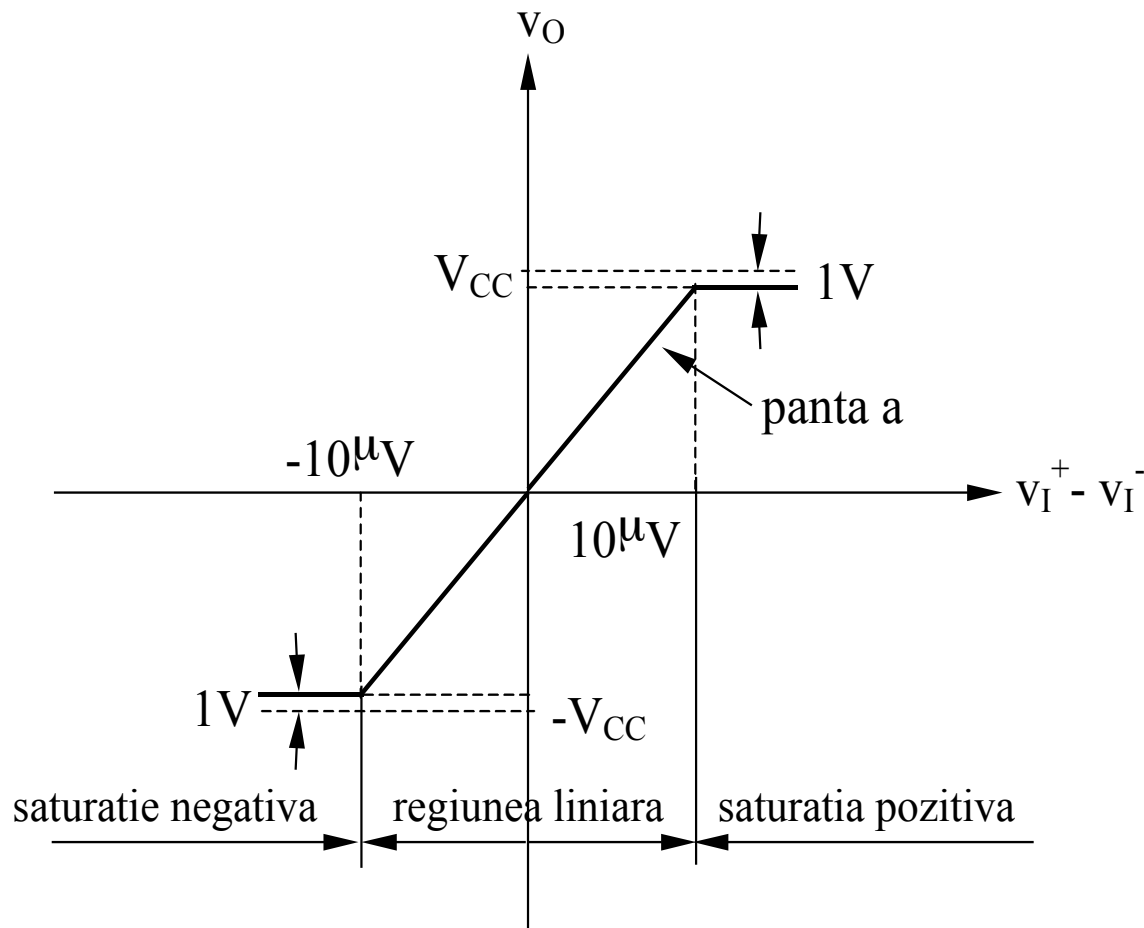
$$v_o = a(v_i^+ - v_i^-)$$

In saturatia negativa:

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

In saturatia pozitiva:

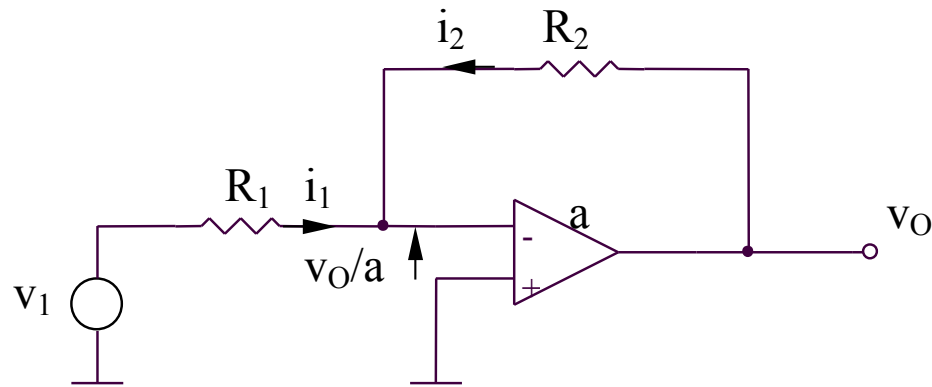
$$v_o \cong V_{CC} - 1V$$



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



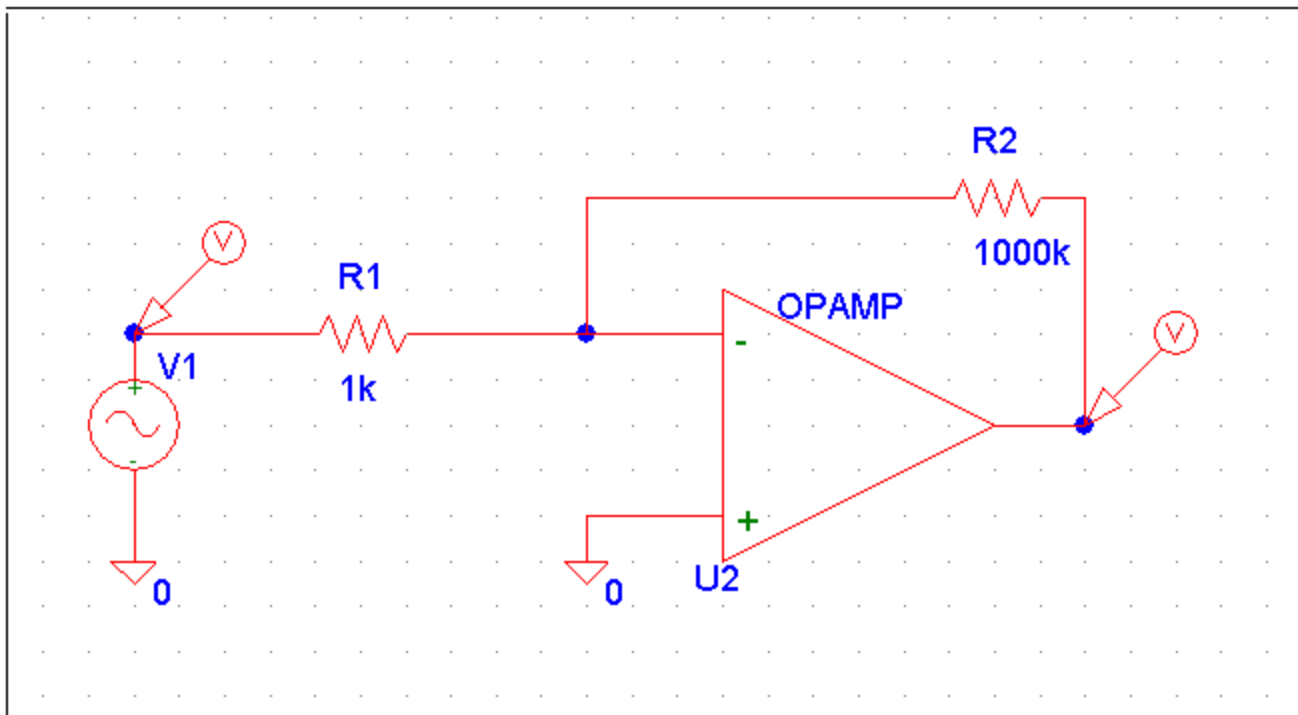
$$\frac{v_1 + \frac{v_O}{a}}{R_1} + \frac{v_O + \frac{v_O}{a}}{R_2} = 0 \Rightarrow$$

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

**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)

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

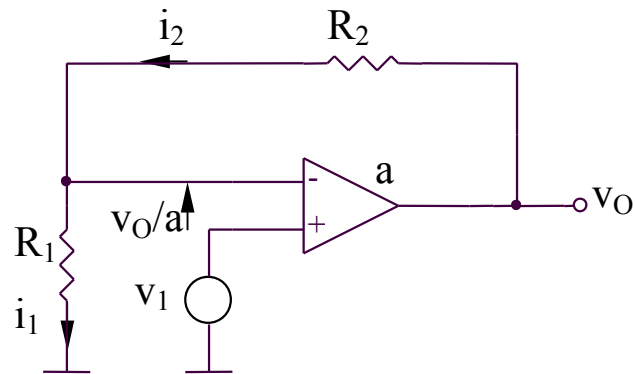
$$A_{real} = -10^3 \frac{1}{1 + \frac{1}{10^3} \left(1 + 10^3 \right)}$$

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

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.

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

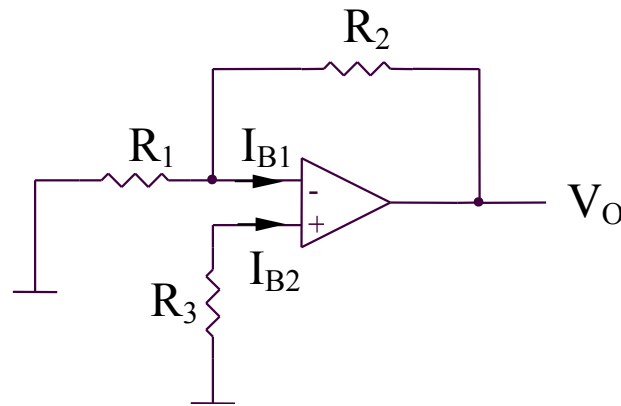
Valori tipice:

- 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



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

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

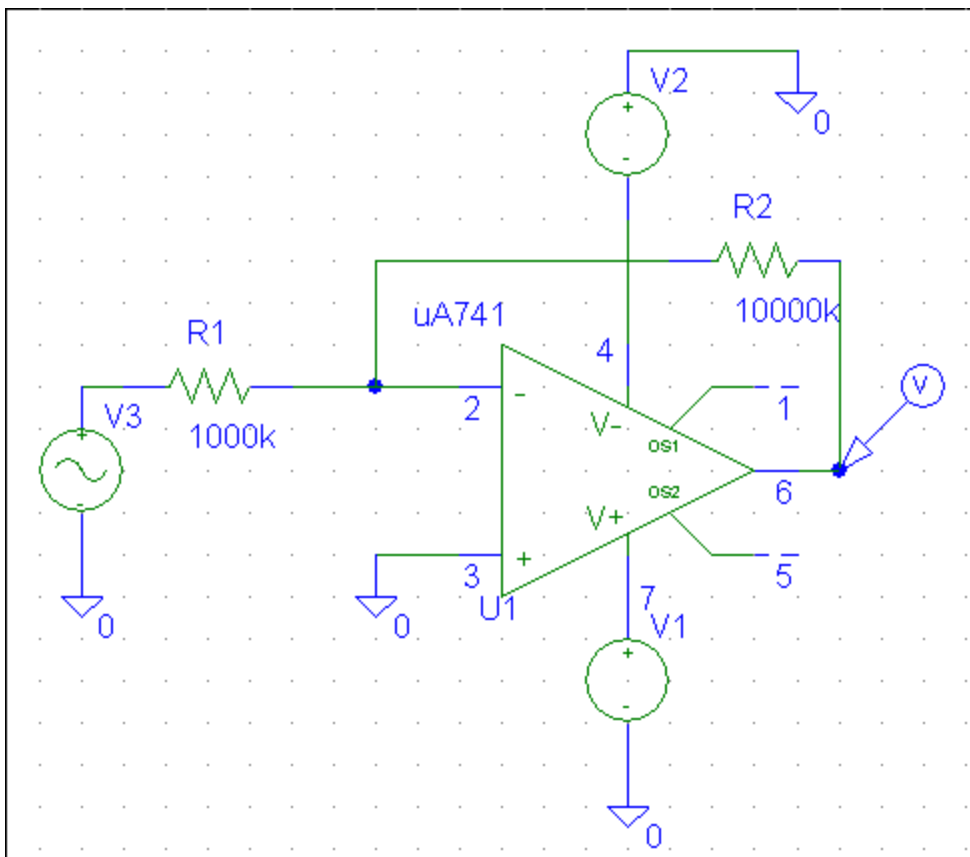
se obtine:

$$V_O = 0$$

**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)



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

$$V_{AMPL} = 5mV$$

$$f = 1kHz$$

$$I_B = 80nA$$

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

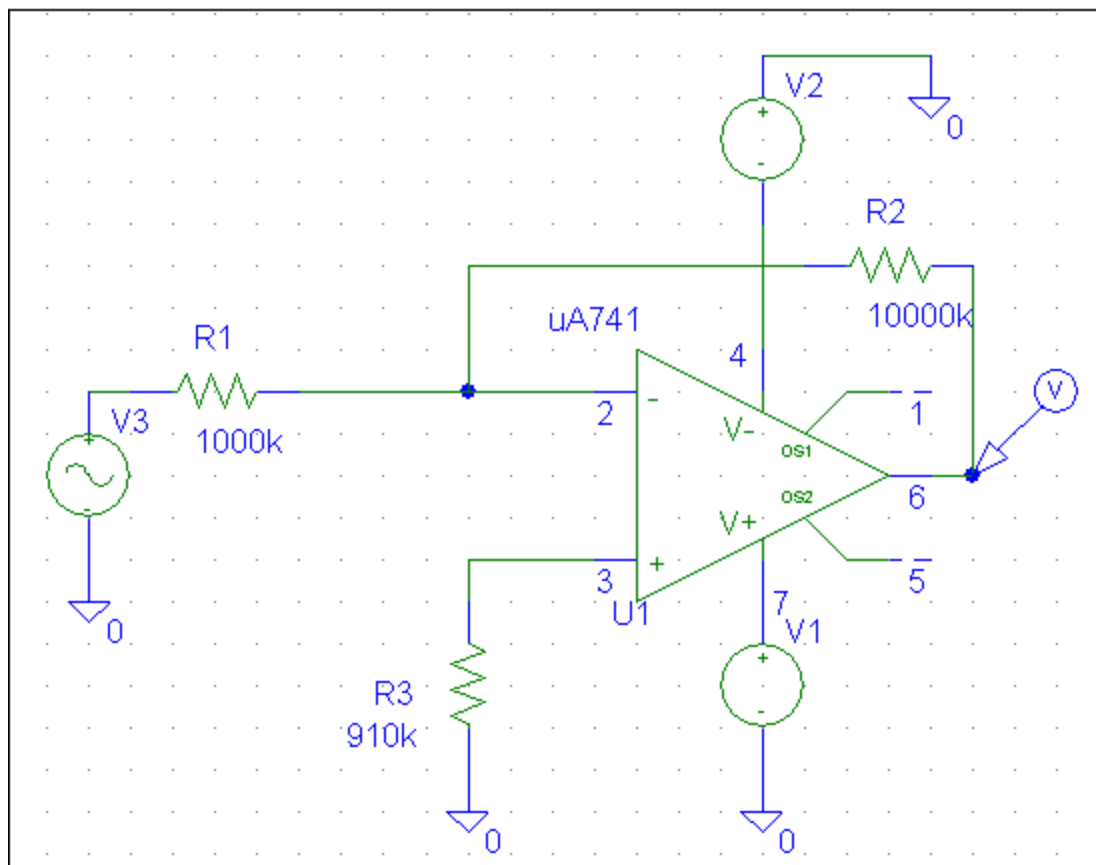
$$R_3 = 0 \Rightarrow \Delta V_O = I_{B1}R_2$$

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

$$\Delta V_O = 800mV$$

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)



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

$$V_{AMPL} = 5mV$$

$$f = 1kHz$$

$$I_B = 80nA$$

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

$$R_3 = R_1 // R_2$$

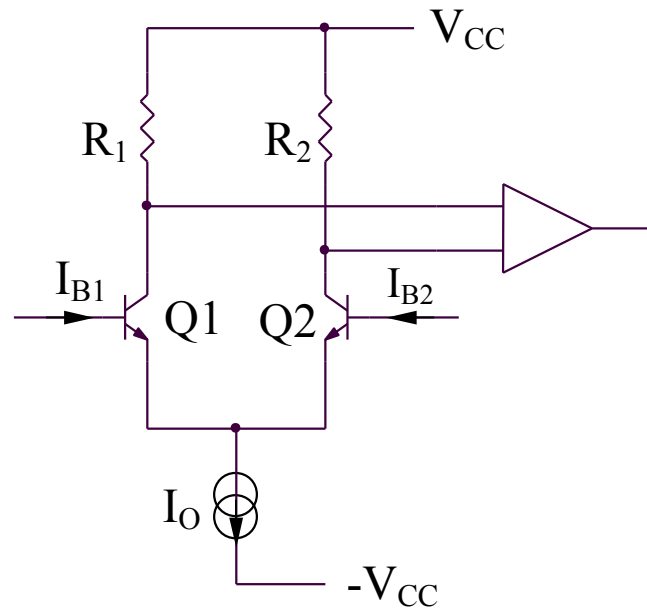
$$R_3 = 1M\Omega // 10M\Omega$$

$$R_3 \cong 910k\Omega$$

$$\Rightarrow \Delta V_O = 0$$

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_{ICmax}]

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.

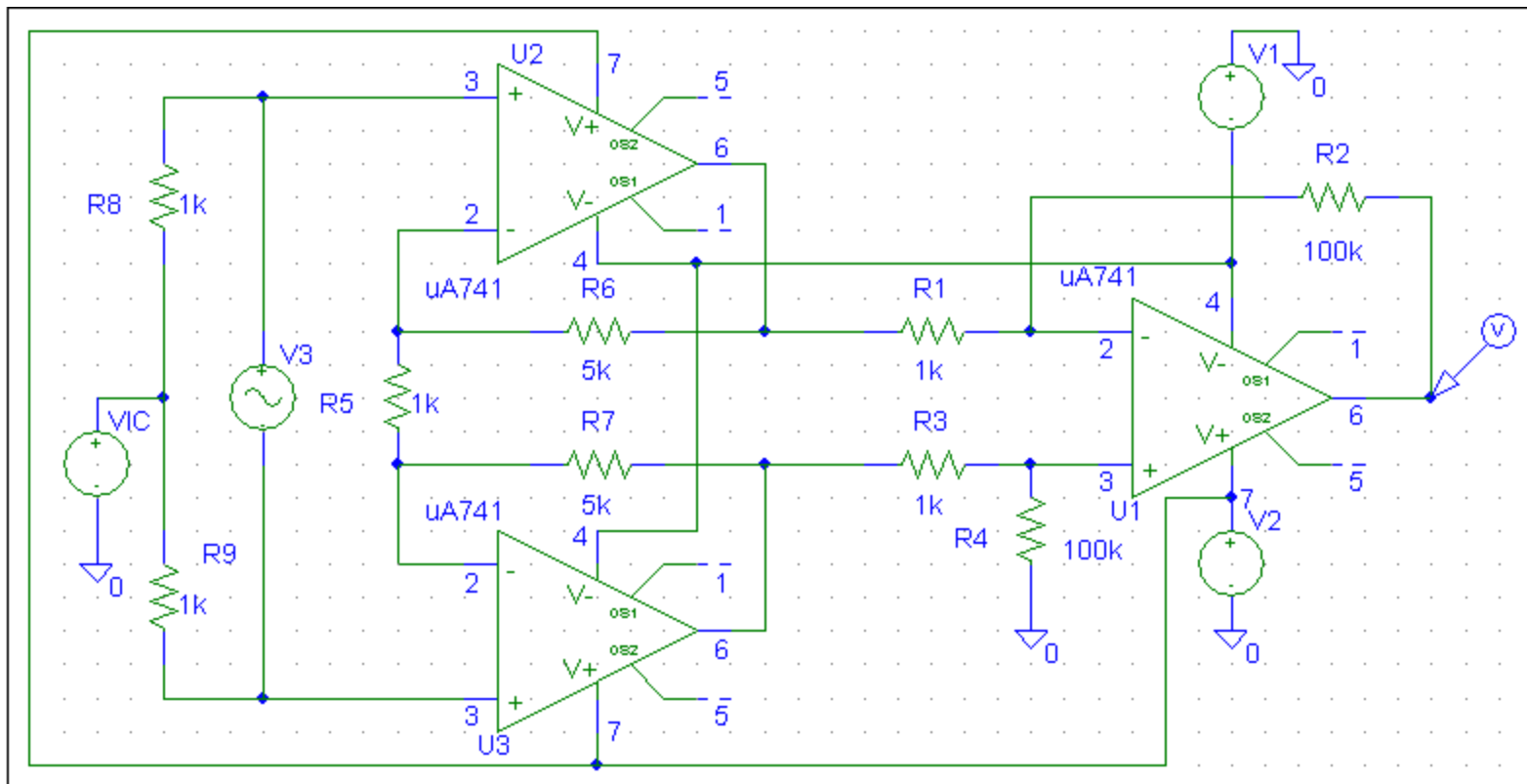
SIMULARI pentru evaluarea limitarilor introduse de $[v_{ICmin} v_{ICmax}]$

2.4. Deviati de la idealitate si limitari ale AO real

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

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

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



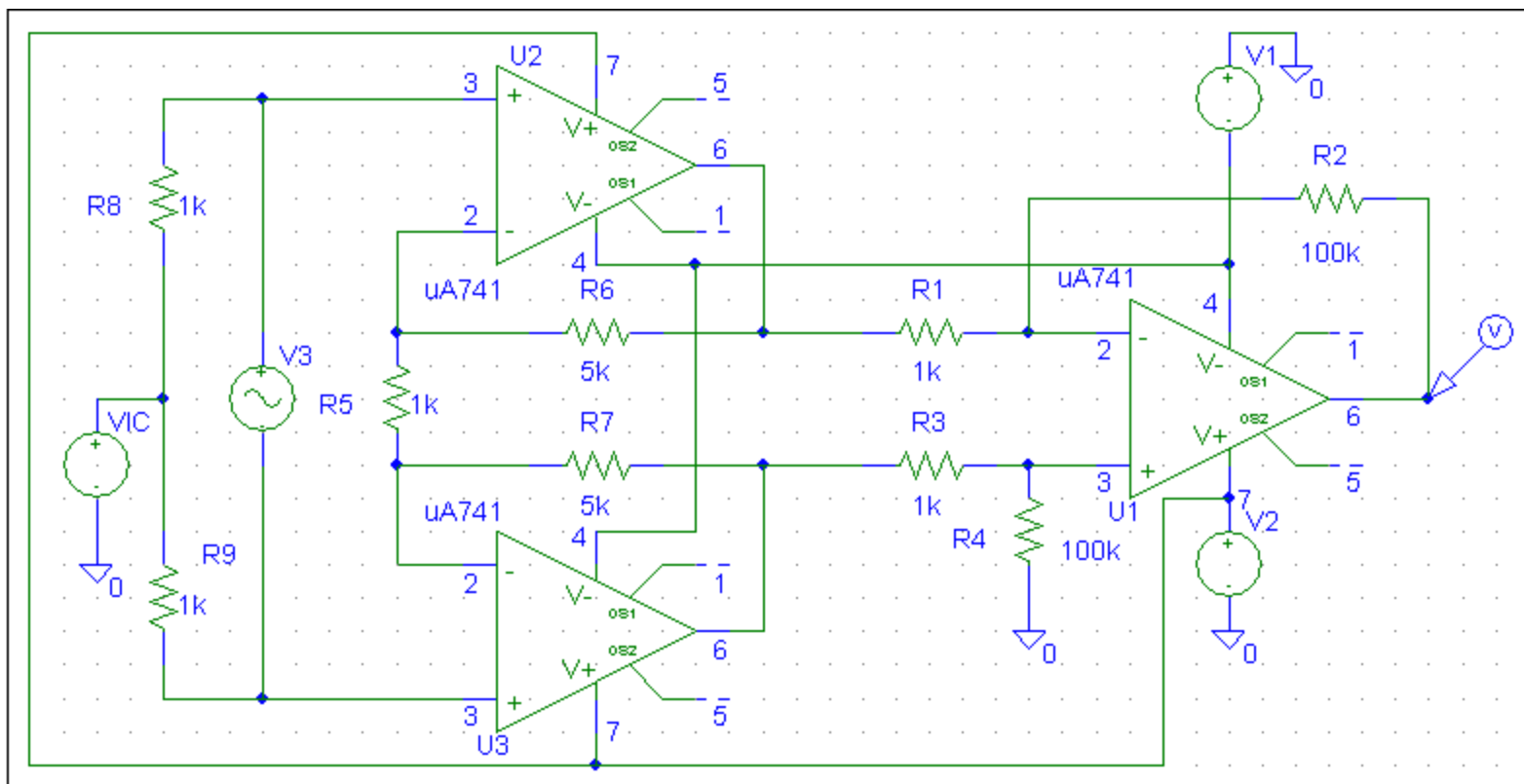
$$v_3(t) = V_{AMPL} \sin(2\pi f t) \quad V_{AMPL} = 1mV; f = 100Hz; v_{IC} = 0 \quad A = \frac{v_o}{v_3} = 1100$$

2.4. Deviati de la idealitate si limitari ale AO real

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

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

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



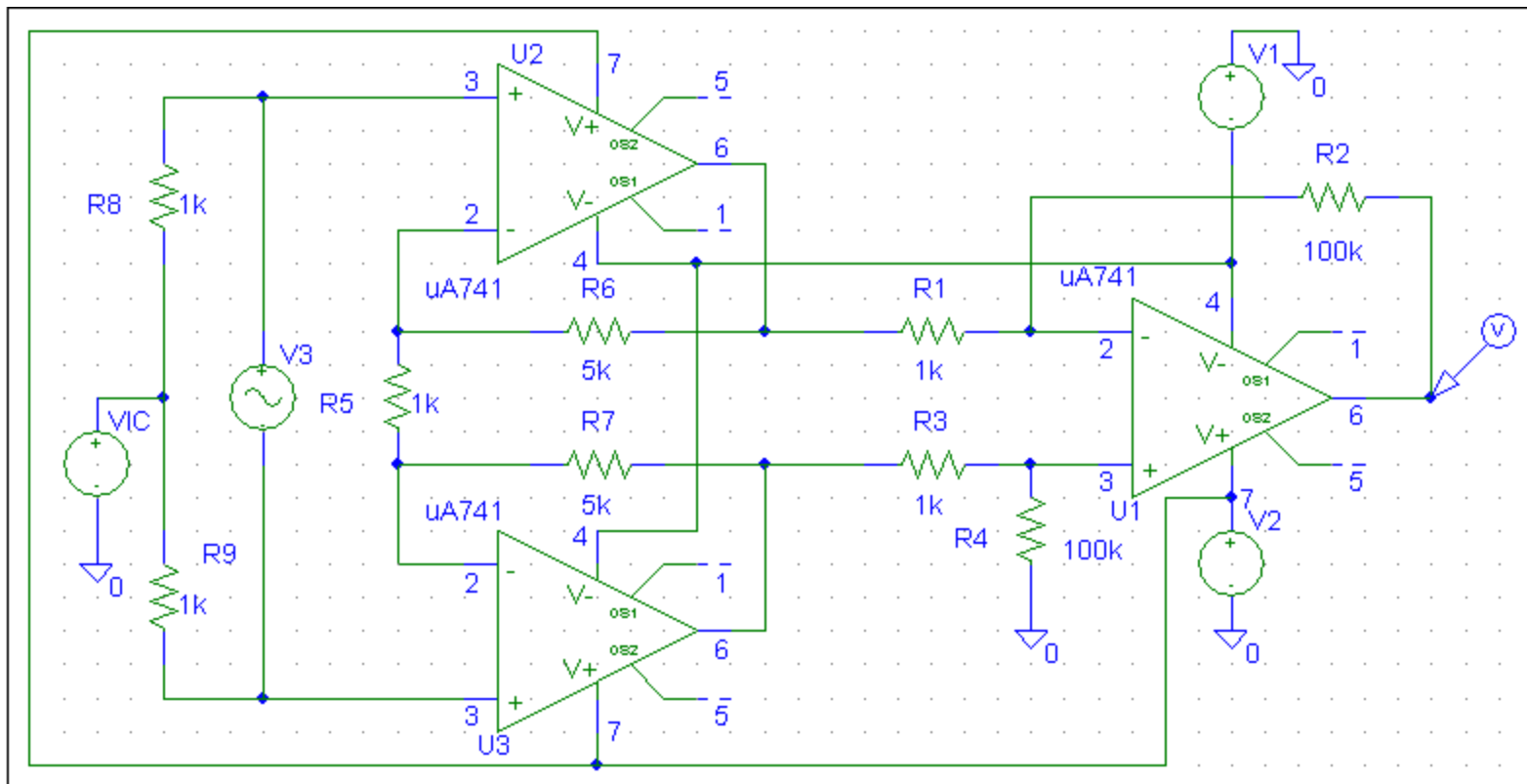
$$v_3(t) = V_{AMPL} \sin(2\pi f t) \quad V_{AMPL} = 1mV; f = 100Hz; v_{IC} = 9V \quad A = \frac{v_o}{v_3} = 1100$$

2.4. Deviati de la idealitate si limitari ale AO real

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

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

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}]

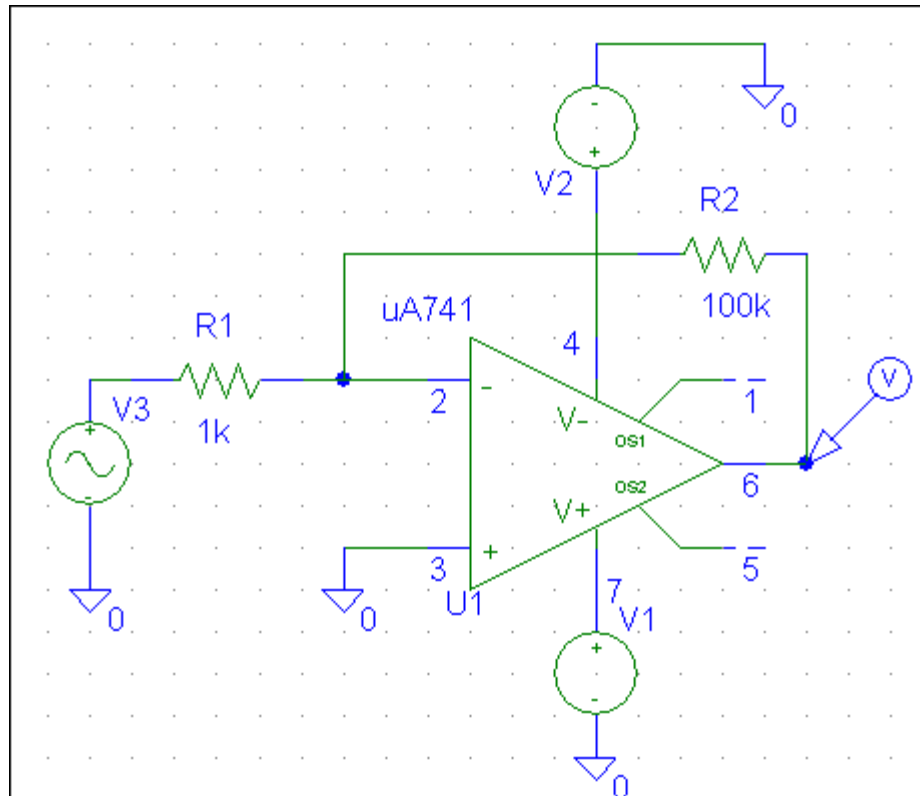
Reprezinta limitele (minima si maxima) intre care poate evolua tensiunea de iesire a AO.

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_{Omin}, v_{Omax}]

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

SIM 2.21: v₃ (t), v_O (t)



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

$$V_{AMPL} = 200mV$$

$$f = 1kHz$$

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

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

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

2.4. Deviati 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.

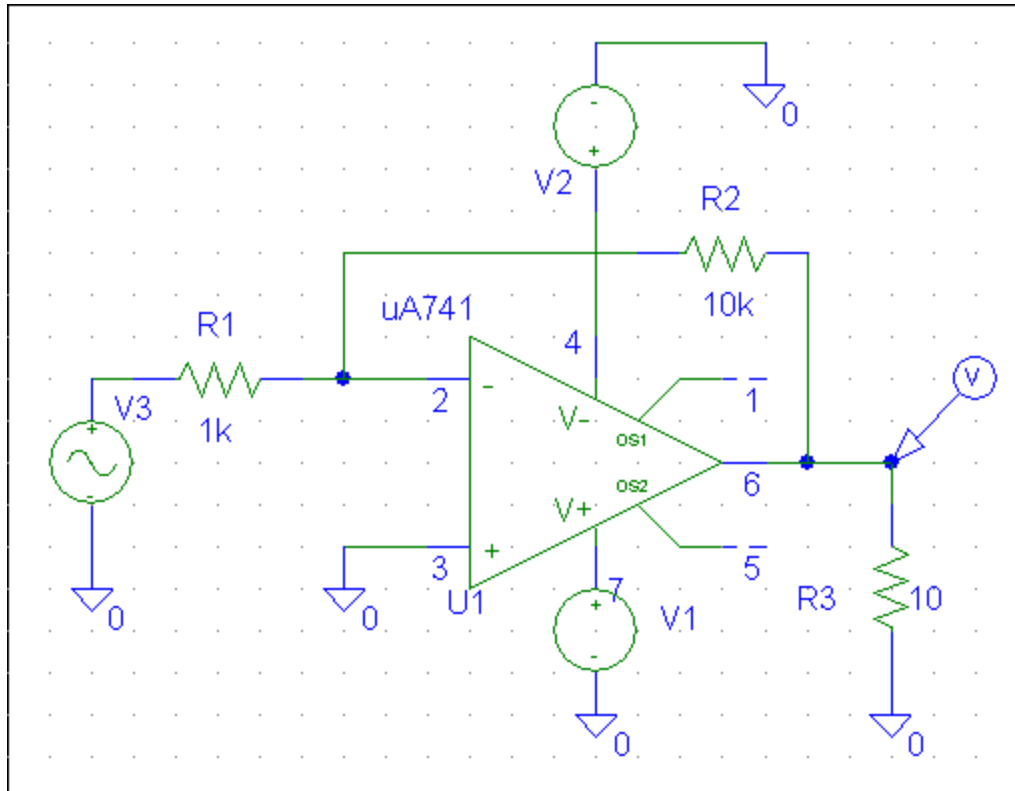
SIMULARI pentru evaluarea curentului maxim de iesire (I_{Omax})

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.

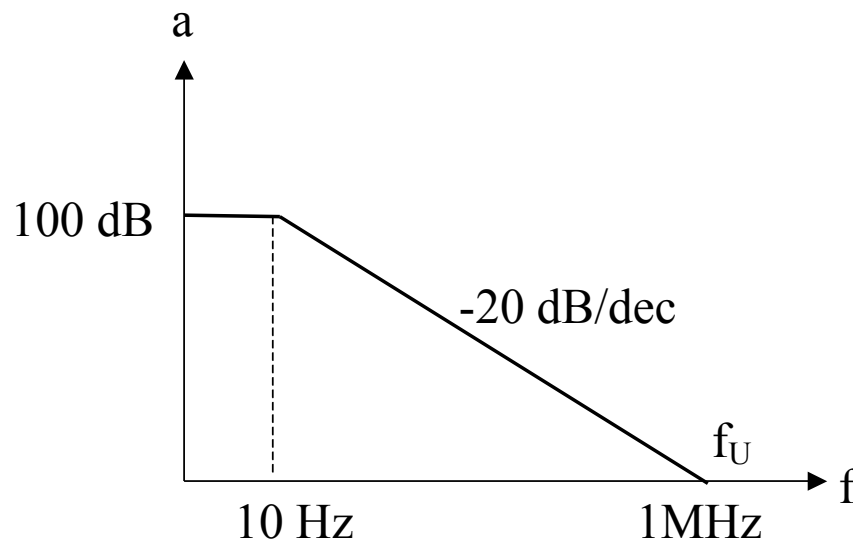
2.4.8. Factorul de rejectie a tensiunii de alimentare (PSRR)

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.

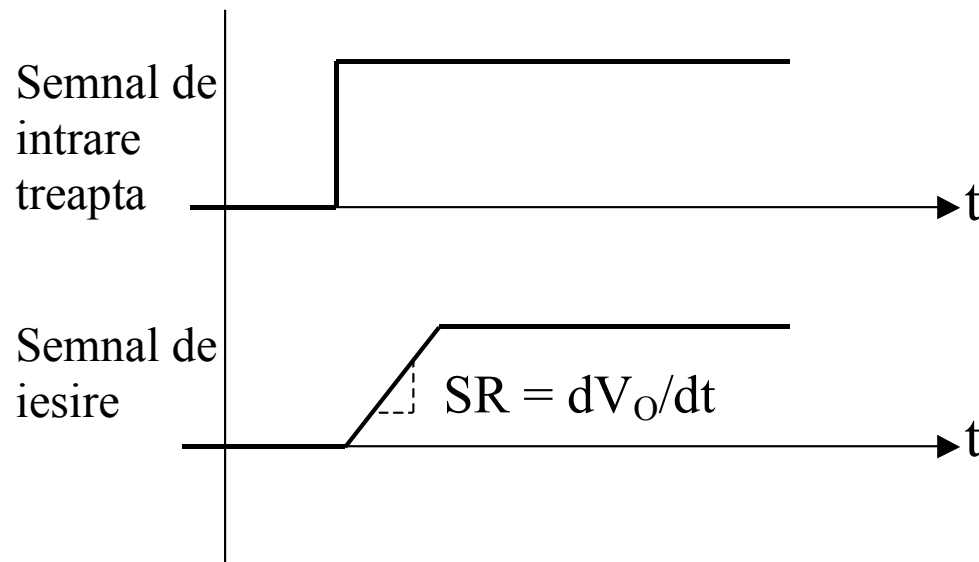


f_U – in domeniul 1MHz – 100MHz

2.4. Deviati de la idealitate si limitari ale AO real

2.4.10. Slew-rate-ul (SR)

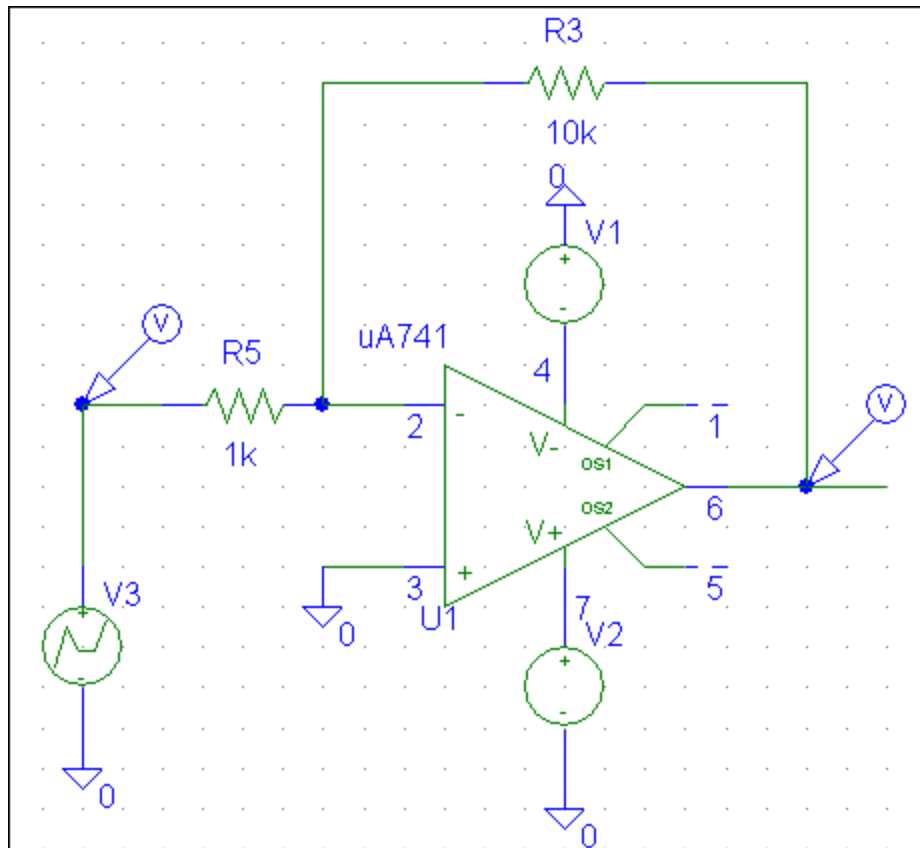
Reprezinta panta maxima a raspunsului tranzitoriu pentru un semnal de intrare de tip treapta.



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

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

$$V_{AMPL} = 1V$$

$$f = 100kHz$$

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

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

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

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

