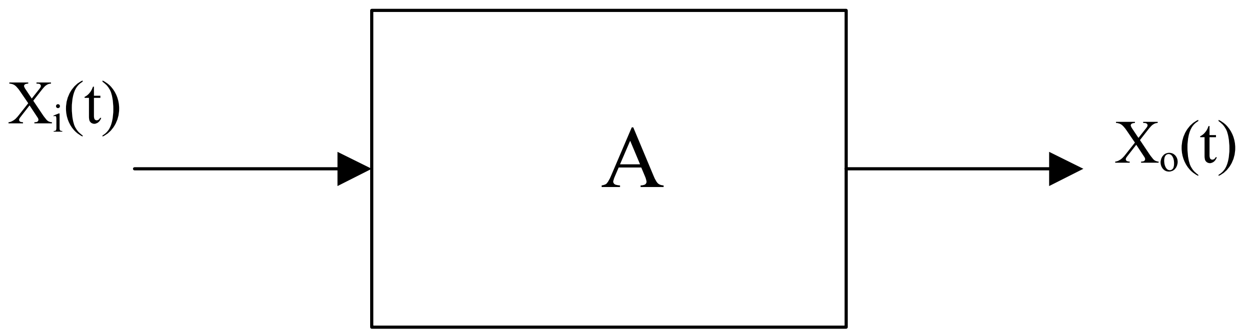
Capitolul 2

Circuite integrate analogice fundamentale

2.1. Amplificatoare de semnal

Amplificatoare liniare



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

$$P_o > P_i$$

2.1.1. Parametri

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

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

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

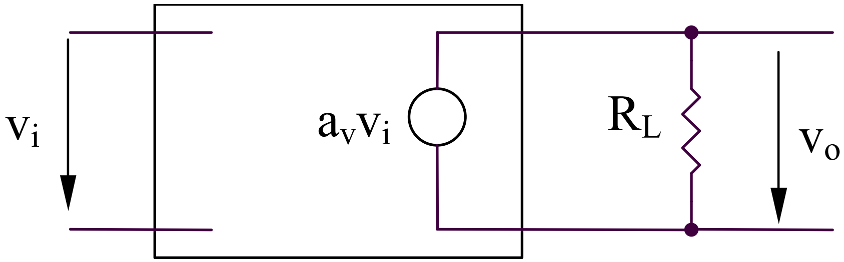
$$Z_o = \frac{v_O}{i_O}$$

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

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

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

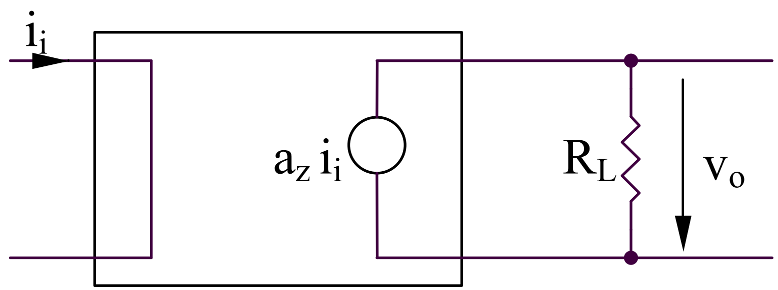
2.1.2. Amplificatoare ideale



Amplificatorul de tensiune

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

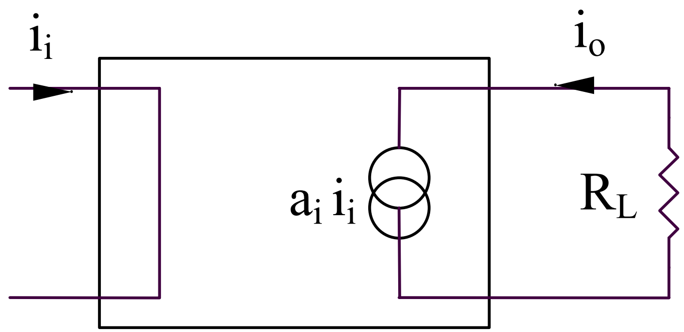
$$R_i \to \infty; R_o = 0$$



Amplificatorul trans-impedanta

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

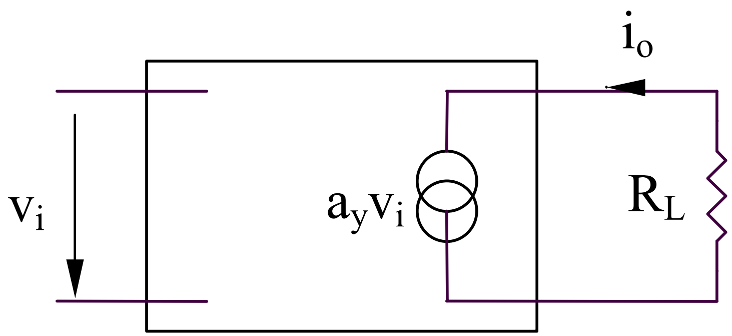
$$R_i = 0; R_o = 0$$



Amplificatorul de curent

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

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

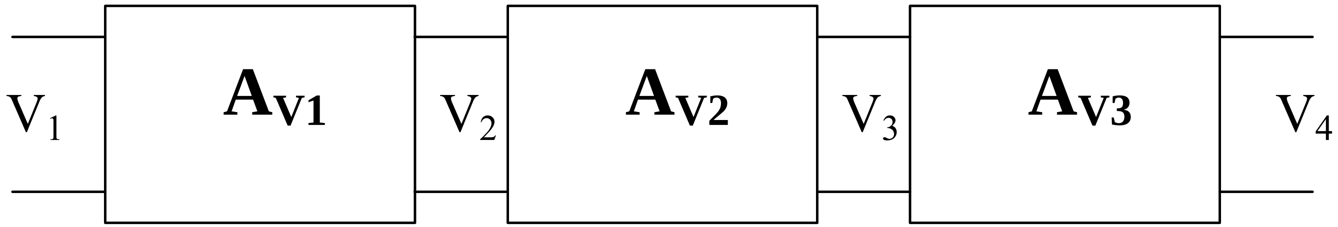


Amplificatorul trans-admitanta

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

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

2.1.3. Cuplarea amplificatoarelor



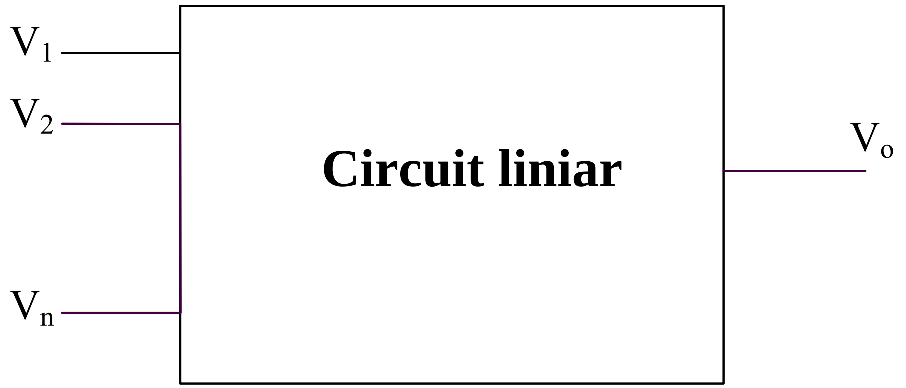
$$A_V = \frac{V_4}{V_1} = A_{V1} A_{V2} A_{V3}$$

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

2.2. Aplicatii ale amplificatoarelor operationale

2.2. Aplicatii ale amplificatoarelor operationale

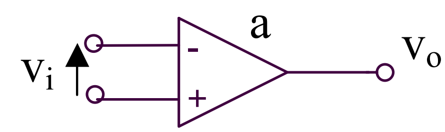
Teorema superpozitiei



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

2.2. Aplicatii ale amplificatoarelor operationale

Un amplificator operational ideal in bucla deschisa este caracterizat prin:
- amplificare in tensiune infinita
- impedanta de intrare infinita
- impedanta de iesire nula



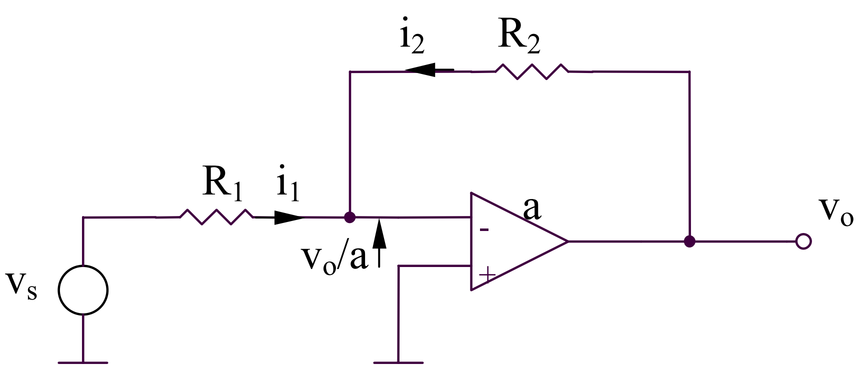
$$a \to \infty$$

$$v_i \to 0$$

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

2.2.1. Amplificatorul inversor

$$\frac{v_s + \frac{v_o}{a}}{R_1} + \frac{v_o + \frac{v_o}{a}}{R_2} = 0 \Rightarrow$$

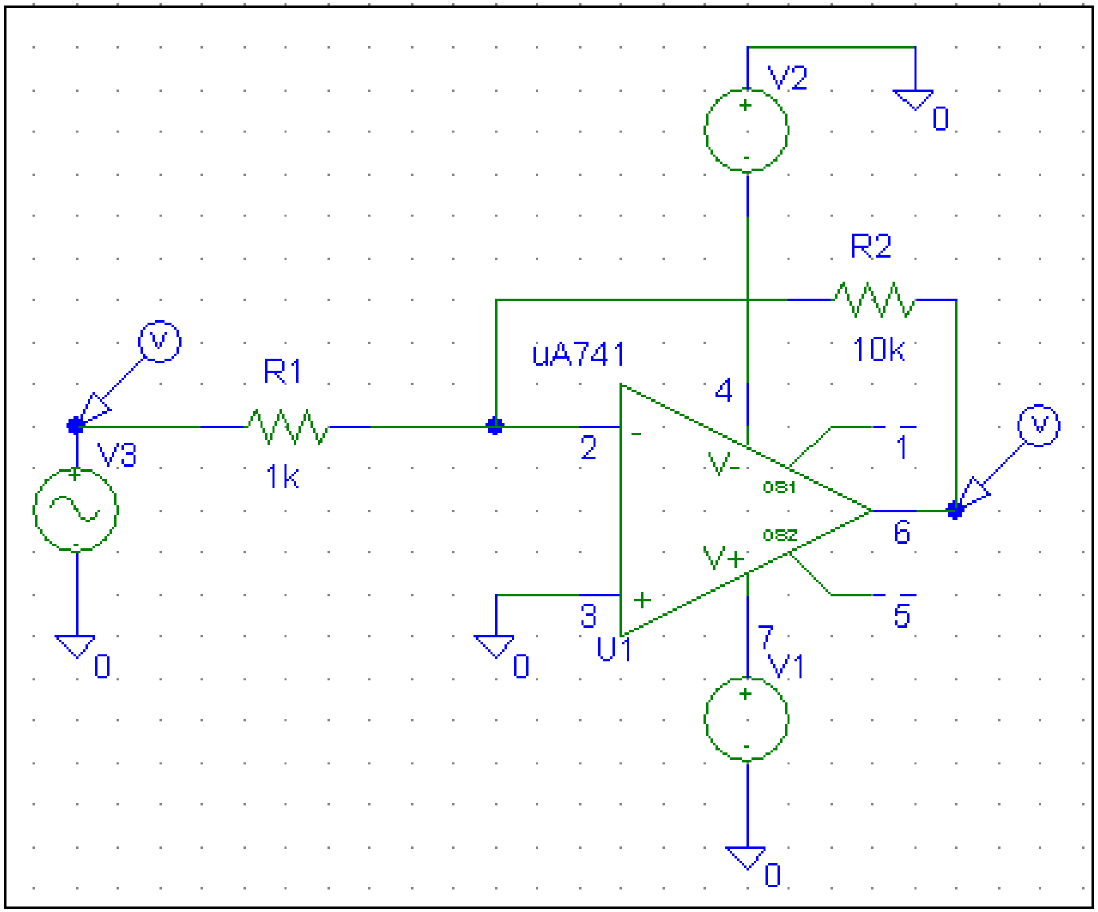


$$\Rightarrow A = \frac{v_o}{v_s} = -\frac{R_2}{R_1} \frac{1}{1 + \frac{1}{a} \frac{R_1 + R_2}{R_1}}$$

SIMULARI pentru amplificatorul inversor

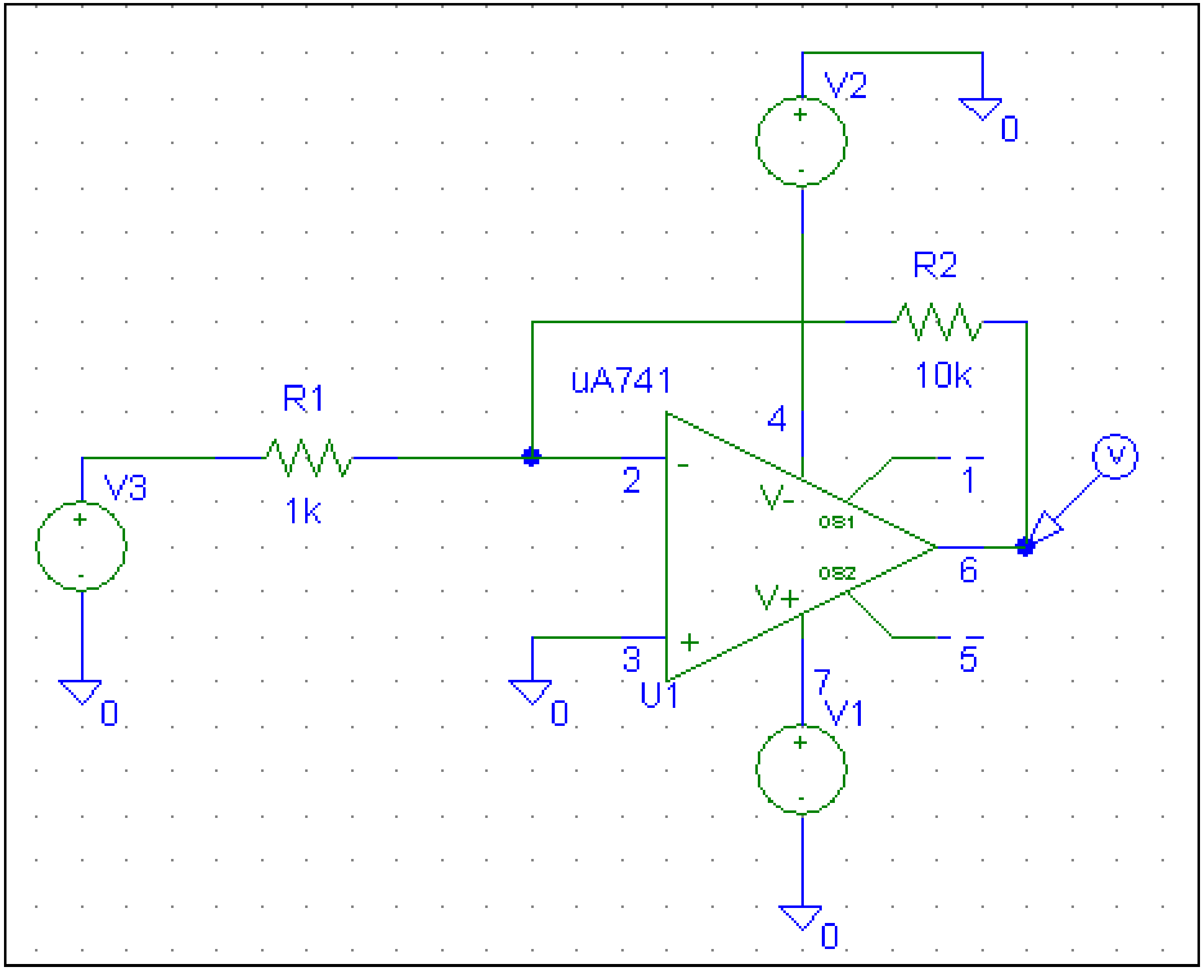
<u>SIMULARI pentru amplificatorul inversor</u>

<u>SIM 2.1</u>: V_3 (t), V_O (t)

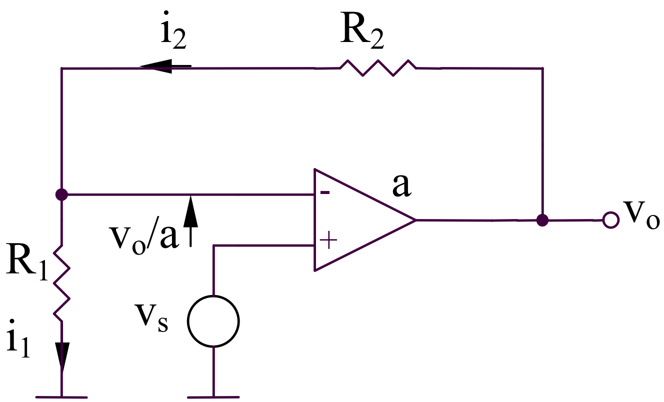


SIMULARI pentru amplificatorul inversor

SIM 2.2: V_O (V_3)



2.2.2. Amplificatorul neinversor



$$\frac{v_s - \frac{v_o}{a}}{R_1} = \frac{v_o - \left(v_s - \frac{v_o}{a}\right)}{R_2} \Rightarrow$$

$$\Rightarrow A = \frac{v_o}{v_s} = \frac{R_1 + R_2}{R_1} \frac{1}{1 + \frac{R_1 + R_2}{aR_1}} = a \frac{1}{1 + af}$$

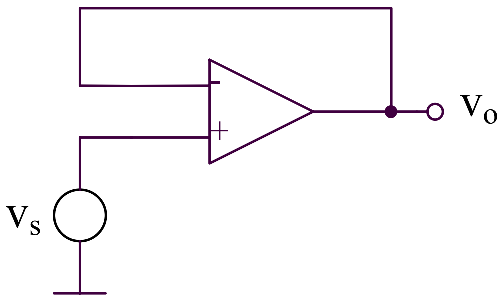
Unde:

$$f = \frac{R_1}{R_1 + R_2}$$

Daca $af >> 1$, rezulta:

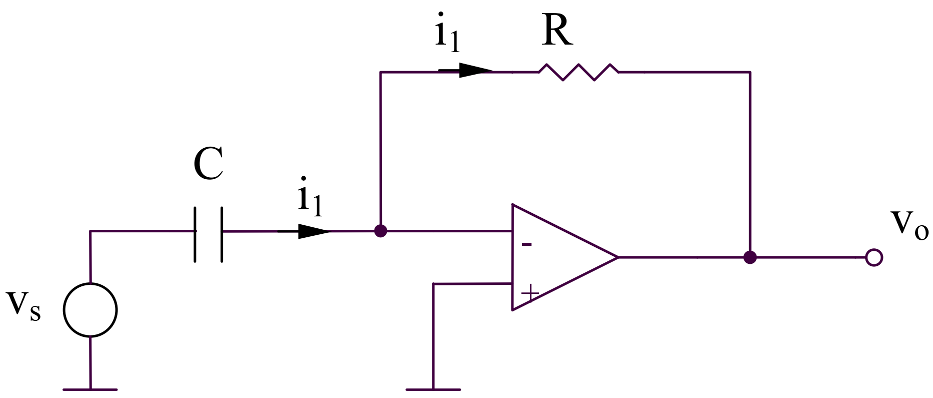
$$A = 1 + \frac{R_2}{R_1}$$

2.2.3. Circuitul repetor



$$v_O = v_s$$

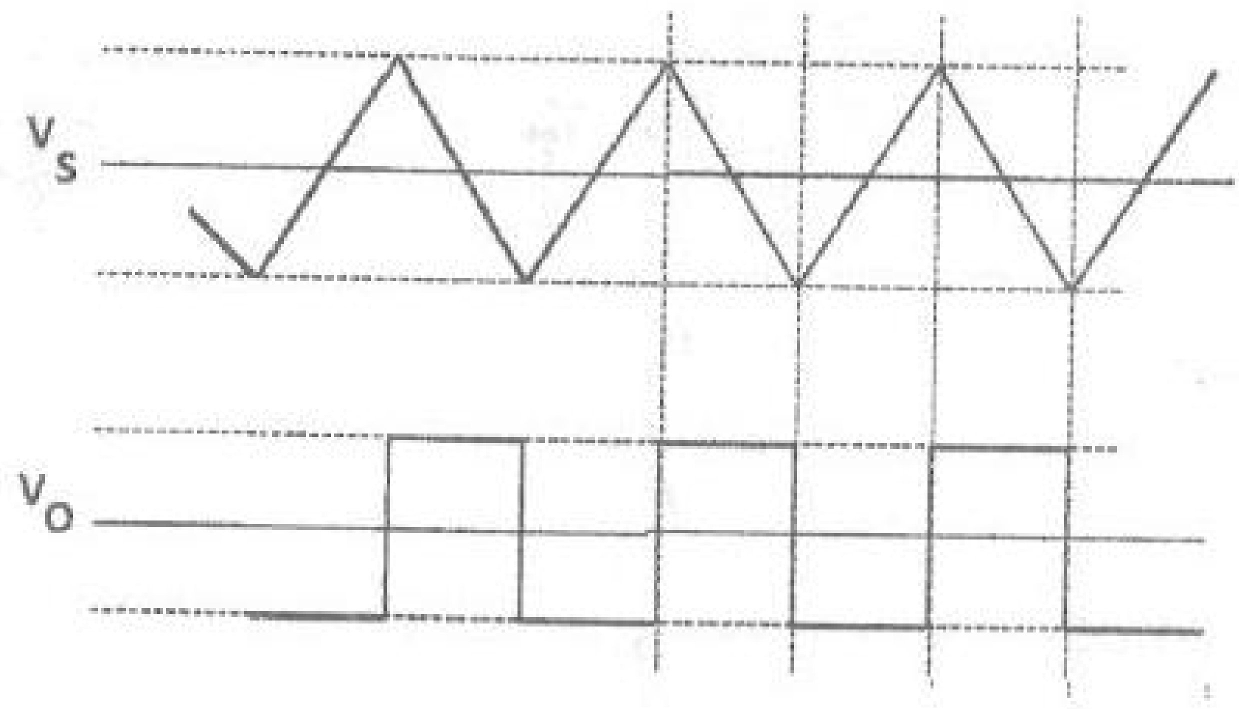
2.2.4. Circuitul de derivare



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

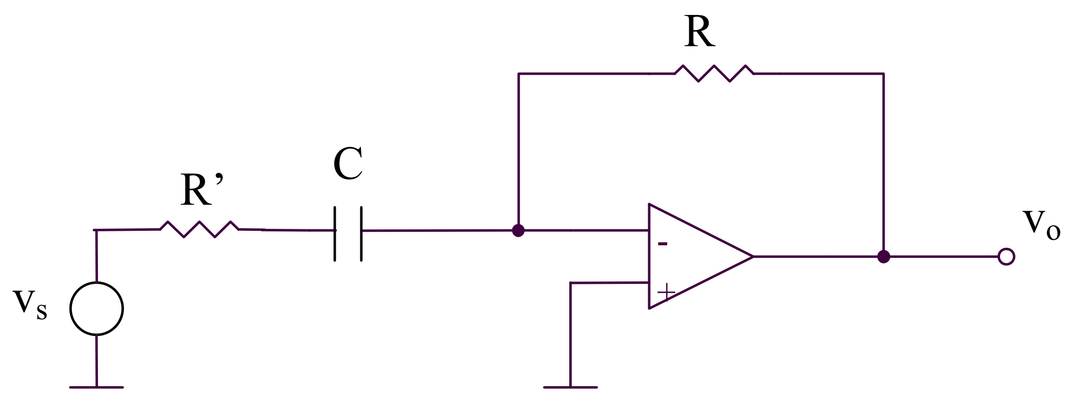
$$v_o = -Ri_1 = -RC\frac{dv_s}{dt}$$

2.2.4. Circuitul de derivare

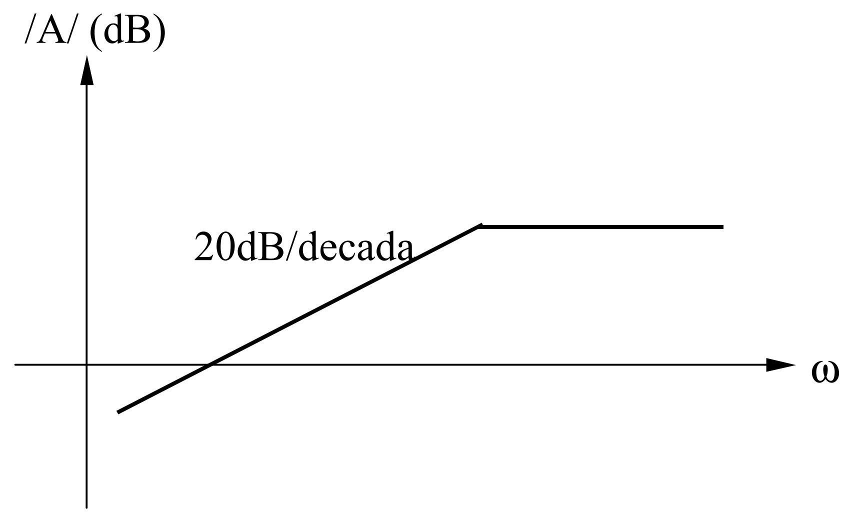


2.2.4. Circuitul de derivare

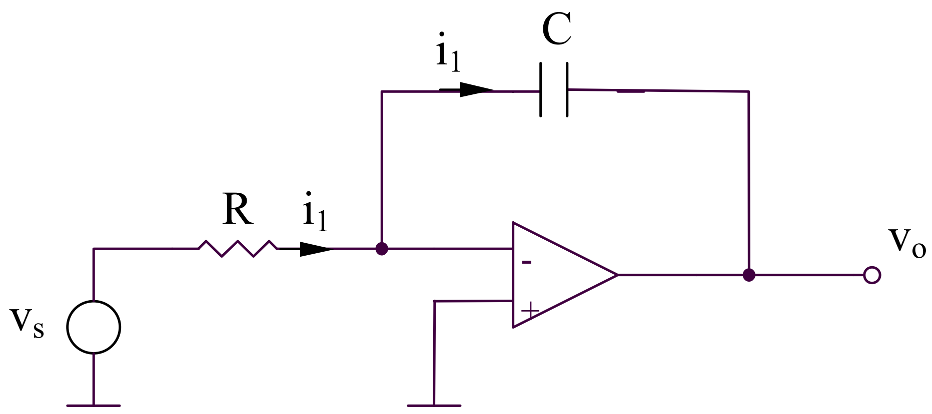
Introducerea R' – pentru cresterea stabilitatii



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



2.2.5. Circuitul de integrare

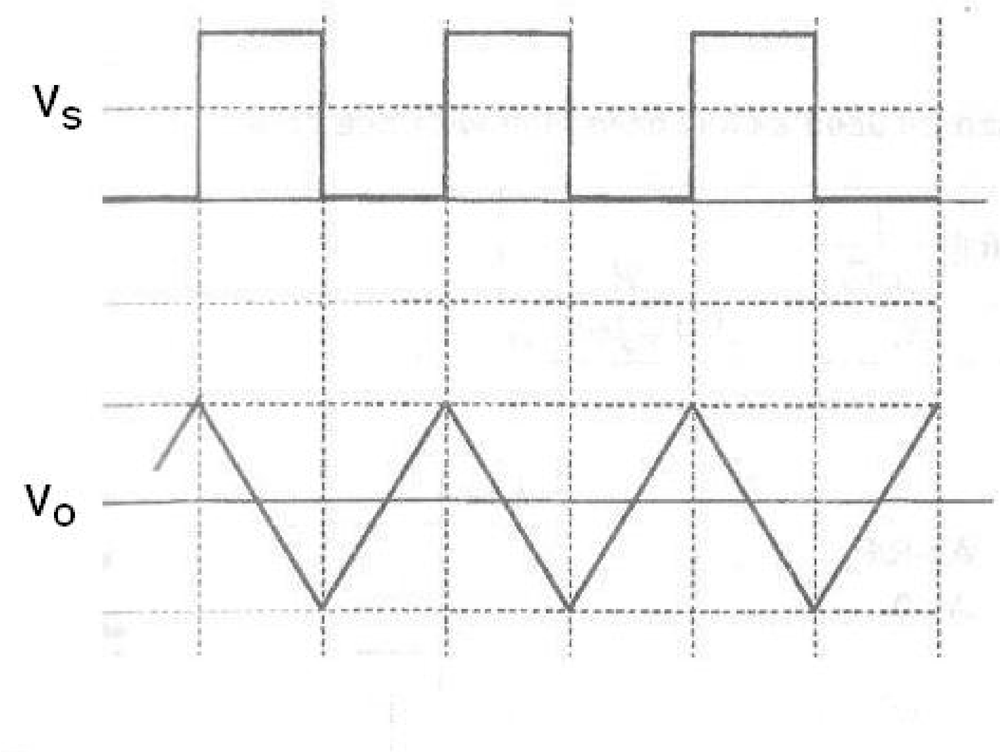


$$i_1 = \frac{v_S(t)}{R}$$

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

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

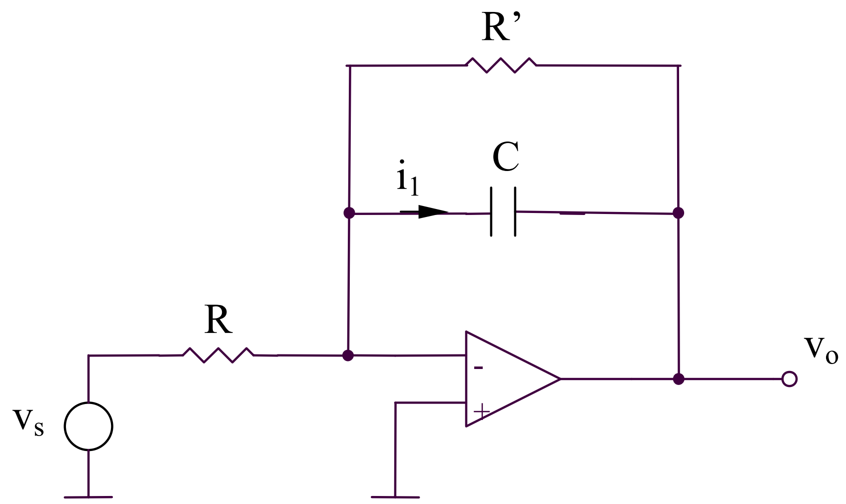
2.2.5. Circuitul de integrare



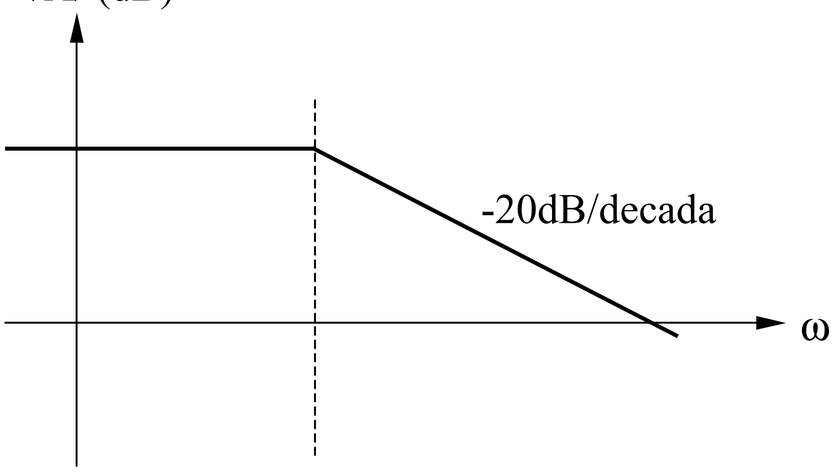
2.2.5. Circuitul de integrare

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

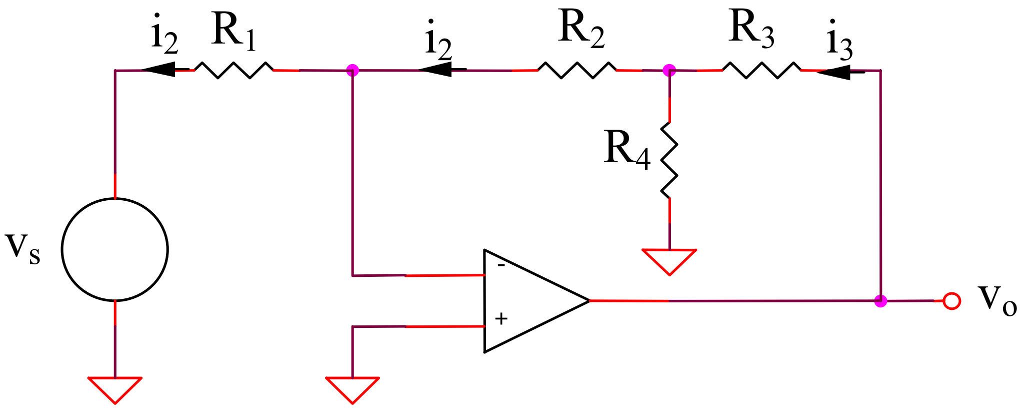
Amplificarea in curent continuu finita, Acc = - R'/R



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



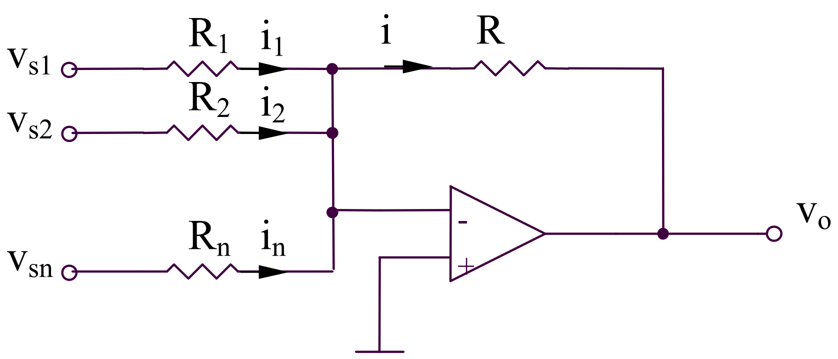
2.2.6. Circuit cu amplificare marita



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

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

2.2.7. Sumatorul inversor



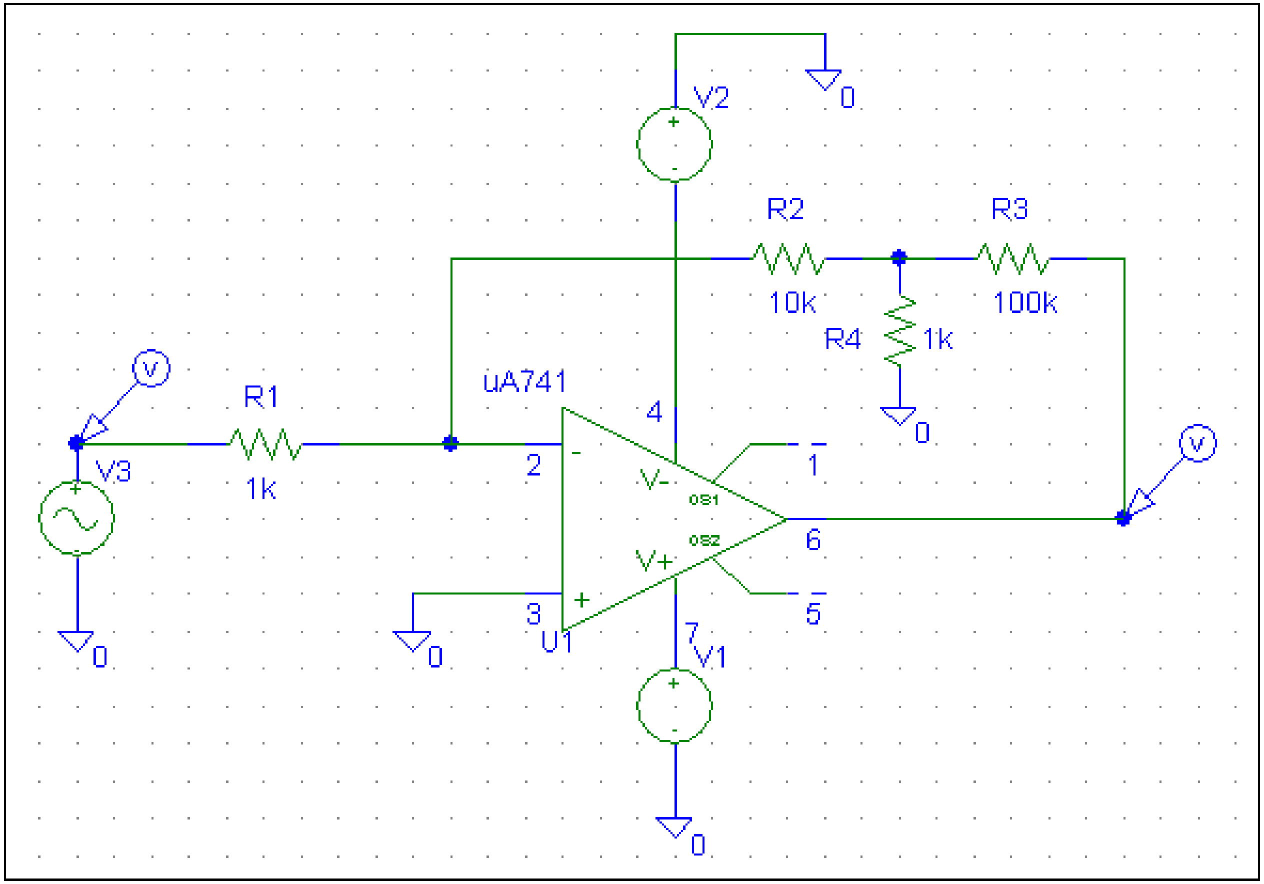
$$i = \sum_{i=1}^{n} i_i = \sum_{i=1}^{n} \frac{v_{si}}{R_i}$$

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

SIMULARI pentru circuitul cu amplificare marita

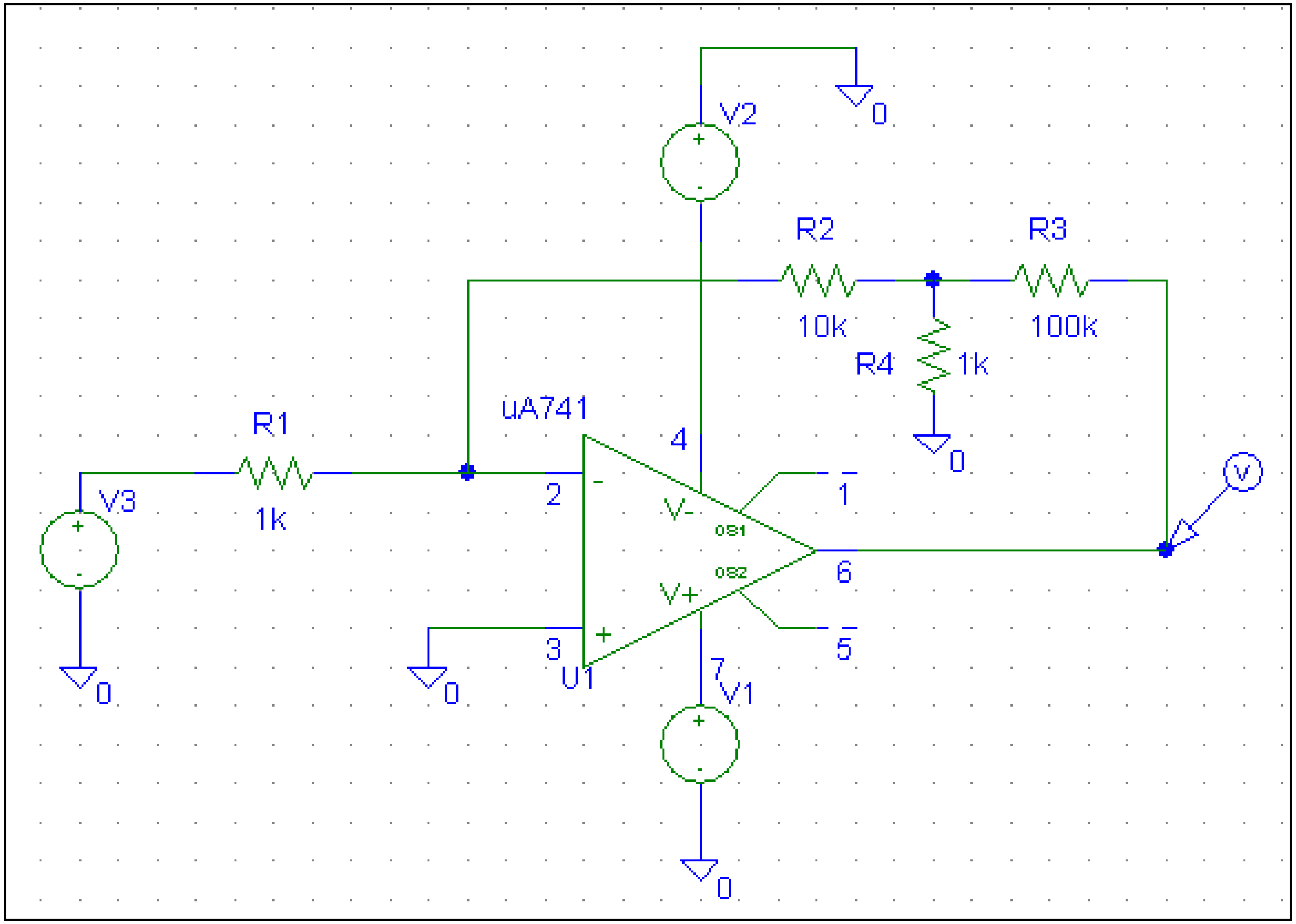
SIMULARI pentru circuitul cu amplificare marita

SIM 2.3: V_3 (t), V_O (t)



SIMULARI pentru circuitul cu amplificare marita

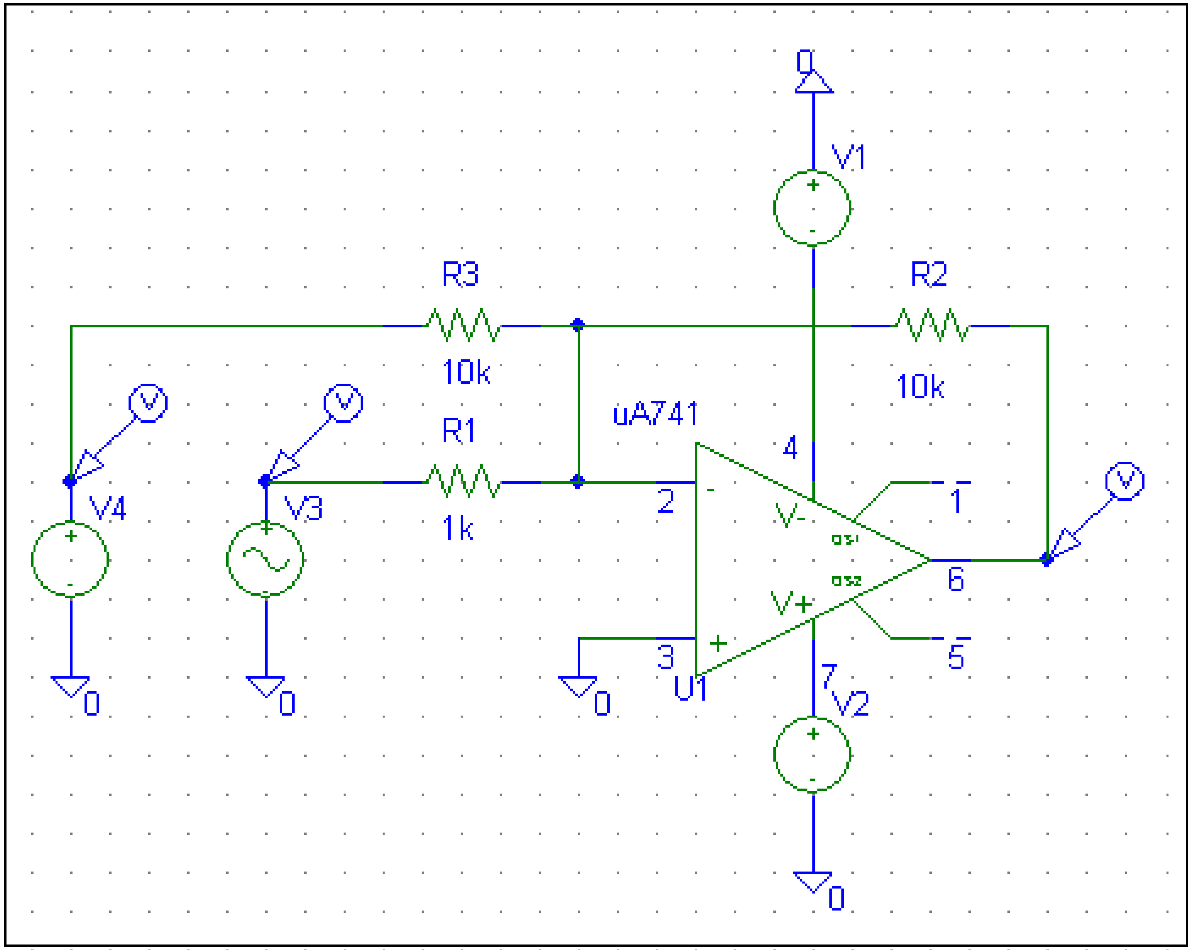
SIM 2.4: V_O (V_3)



SIMULARI pentru sumatorul inversor

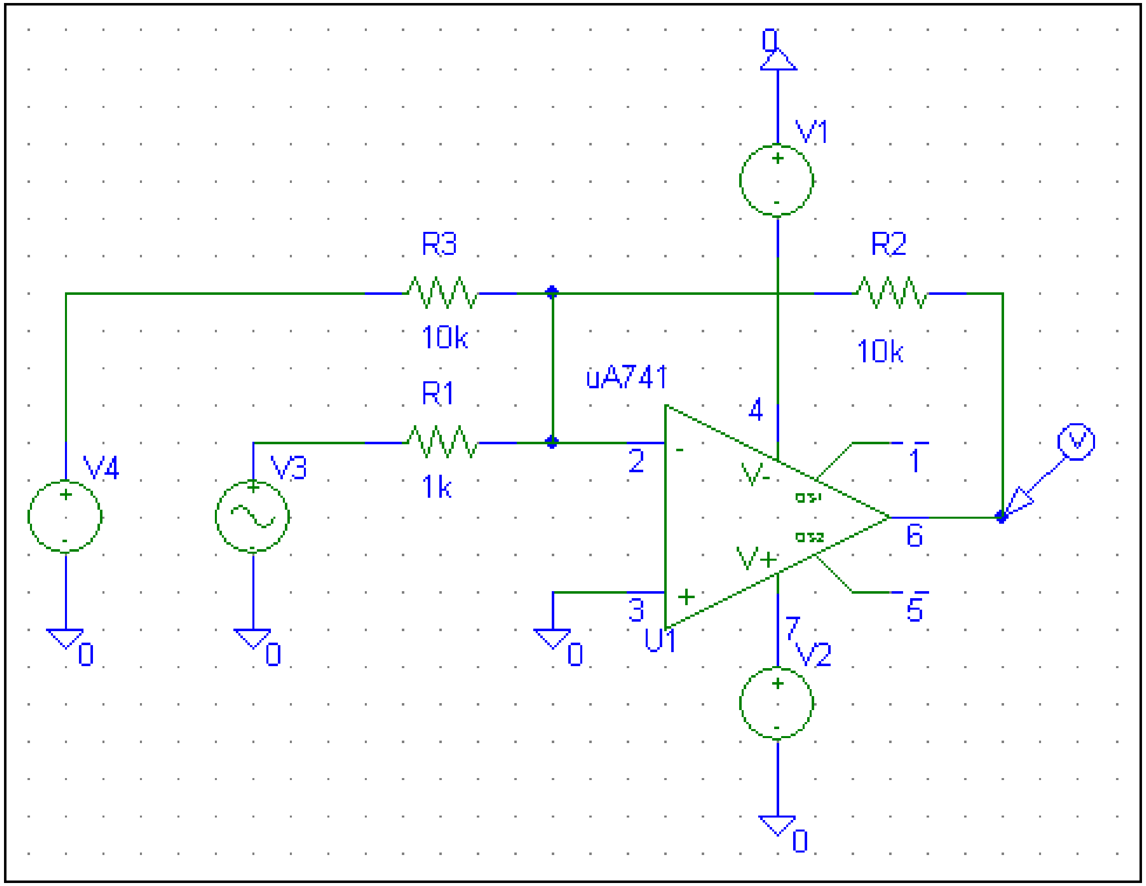
SIMULARI pentru sumatorul inversor

SIM 2.5: V_3 (t), V_4 (t), V_O (t)

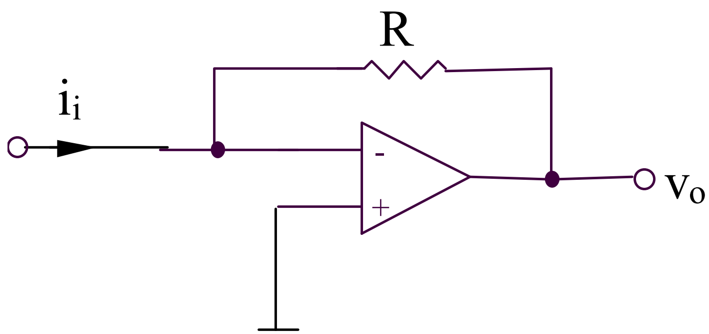


SIMULARI pentru sumatorul inversor

SIM 2.6: V_O (t), V_4 - parameter

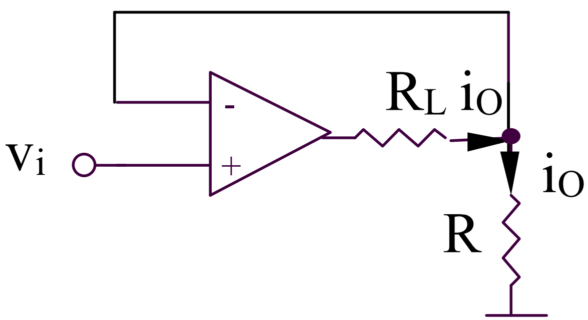


2.2.8. Convertorul curent-tensiune



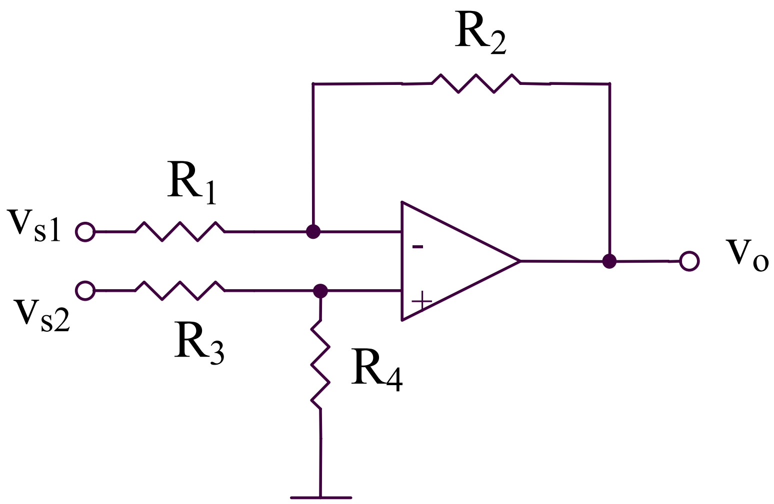
$$v_O = -Ri_i$$

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:

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

este necesara conditia:

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

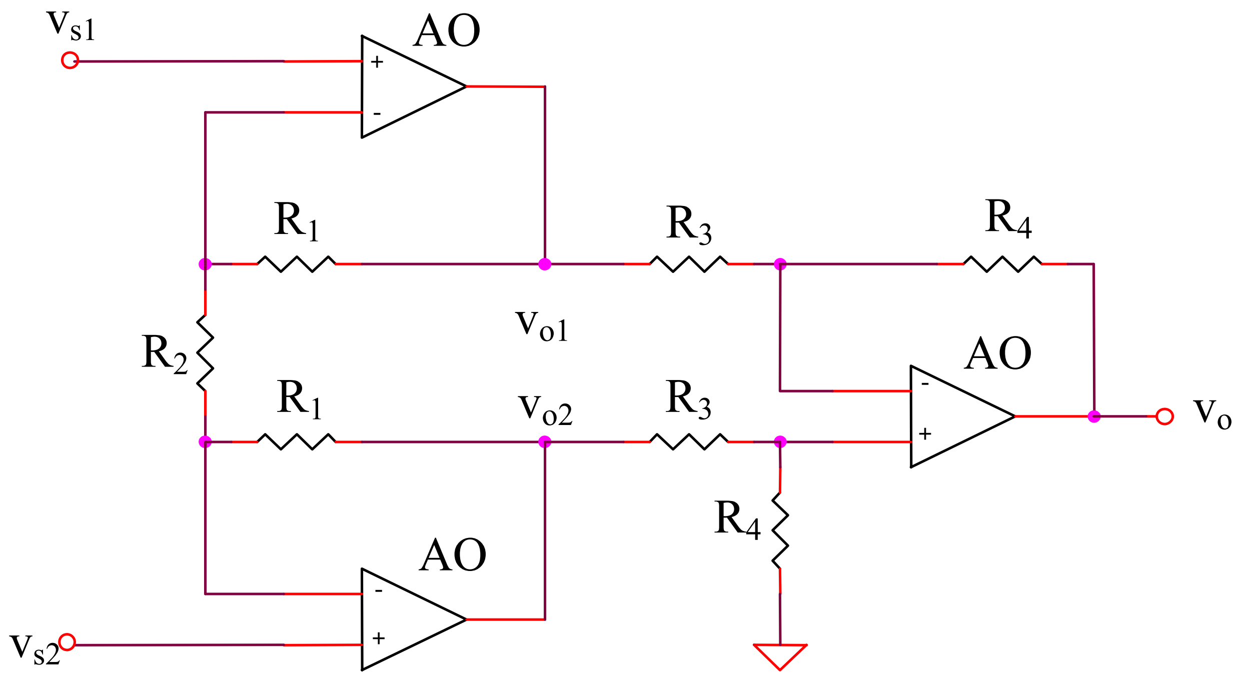
echivalenta cu:

$$R_1 R_4 = R_2 R_3$$

rezultand:

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

2.2.11. Circuitul de diferenta (2)

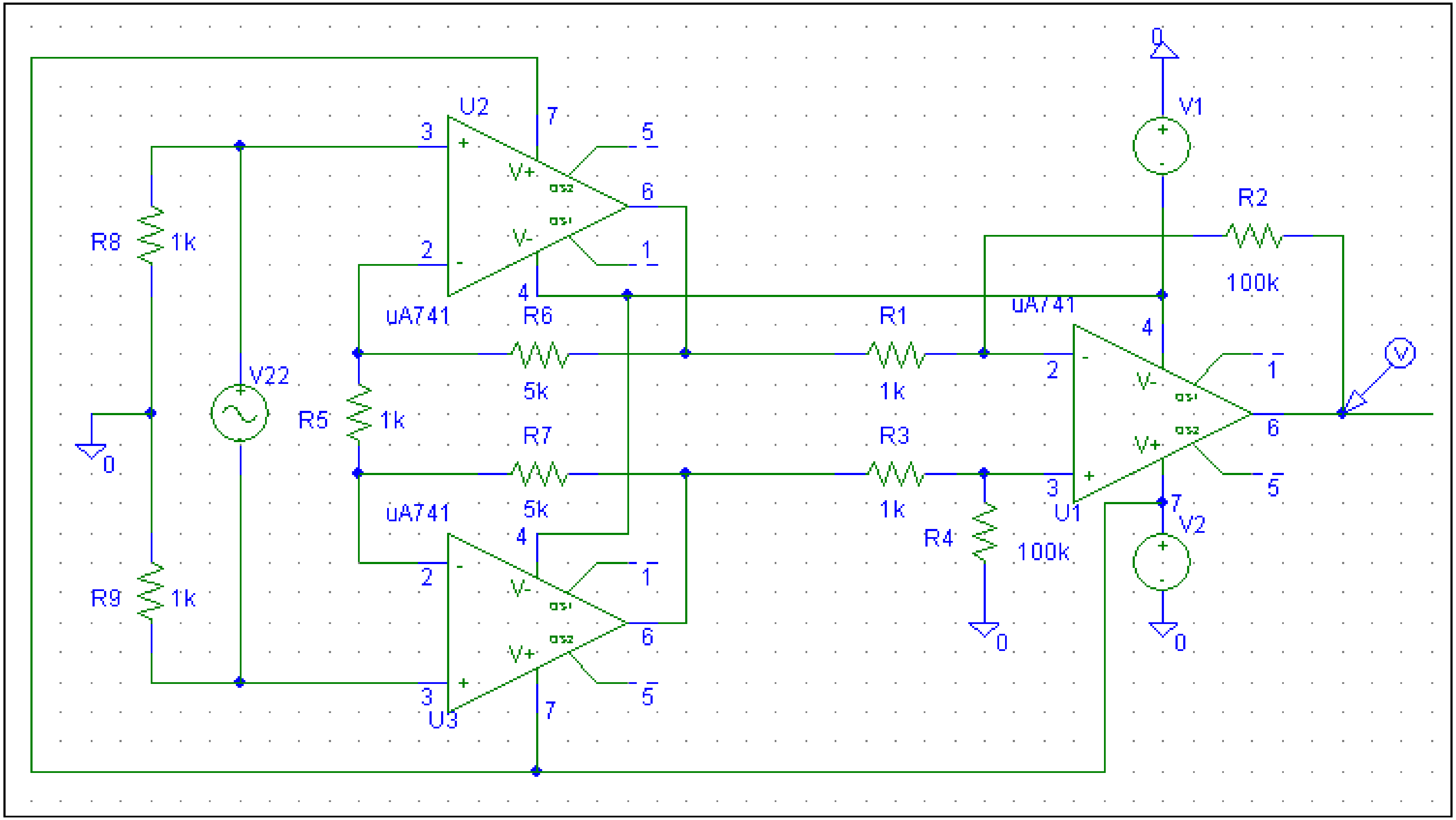


$$\left.\begin{aligned} v_{o1} &= v_{s1}\left(1+\frac{R_1}{R_2}\right)-v_{s2}\frac{R_1}{R_2} \\ v_{o2} &= v_{s2}\left(1+\frac{R_1}{R_2}\right)-v_{s1}\frac{R_1}{R_2} \\ v_o &= \frac{R_4}{R_3}\left(v_{o2}-v_{o1}\right) \end{aligned}\right\} \Rightarrow A=\frac{v_o}{v_{s2}-v_{s1}}=\left(1+2\frac{R_1}{R_2}\right)\frac{R_4}{R_3}$$

SIMULARI pentru circuitul de diferenta (2)

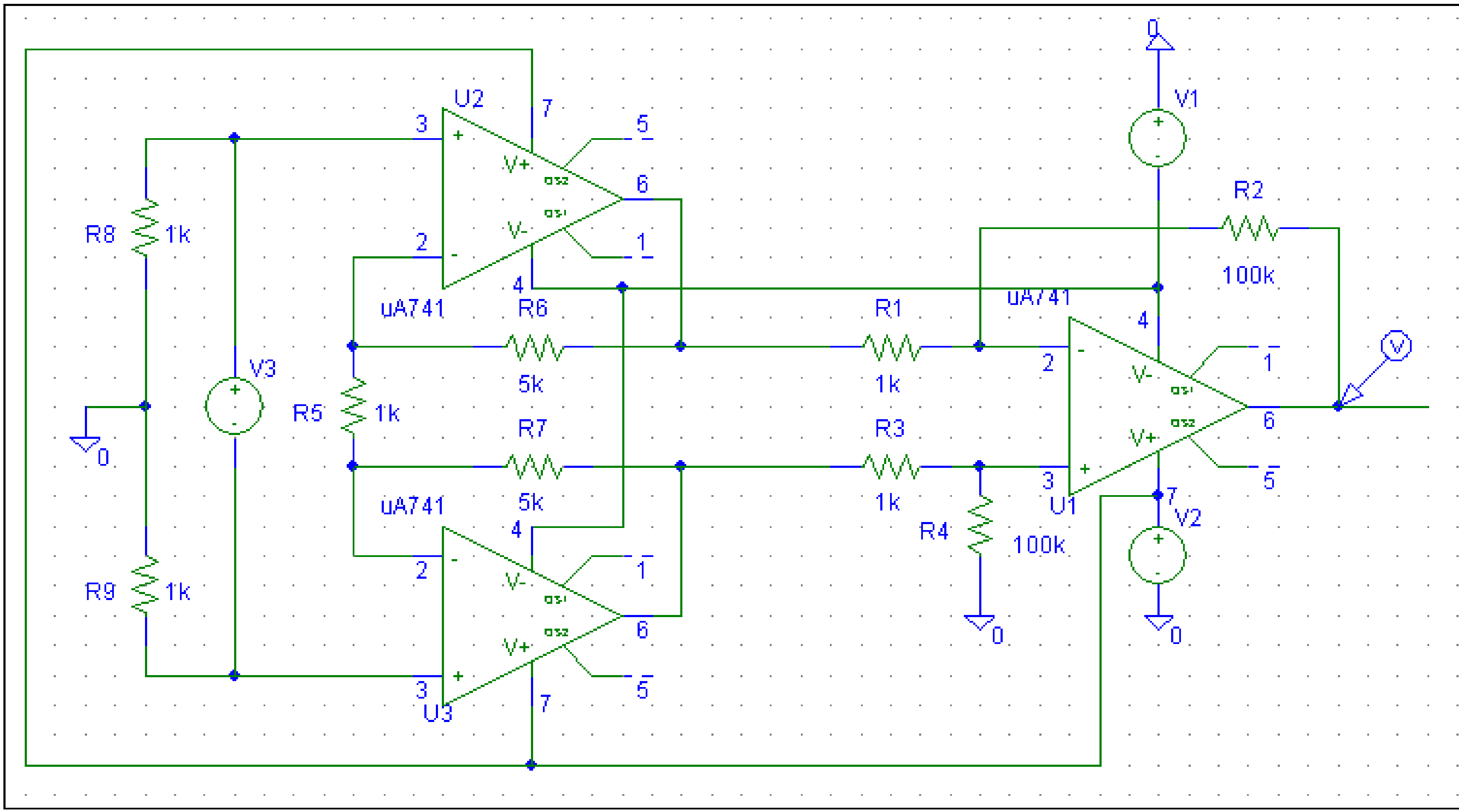
SIMULARI pentru circuitul de diferenta (2)

SIM 2.7: V_O (t)

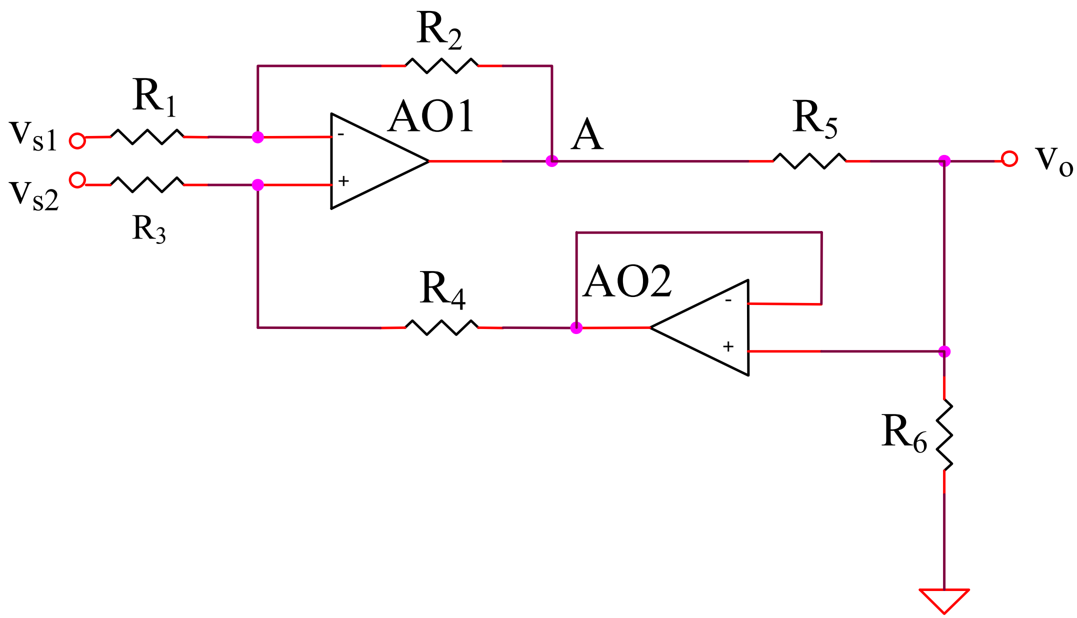


SIMULARI pentru circuitul de diferenta (2)

SIM 2.8: V_O (V_3)



2.2.12. Circuitul de diferenta (3)

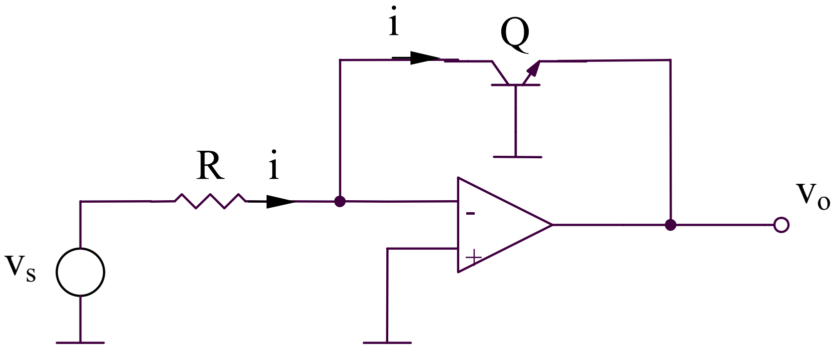


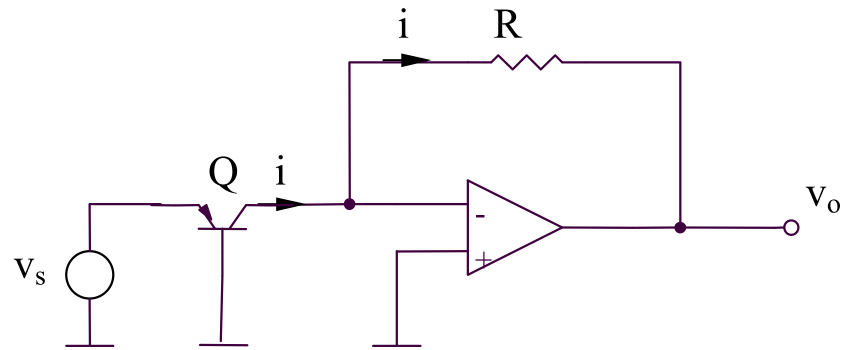
$$\left.\begin{array}{l} v_A = v_{s1}\left(-\dfrac{R_2}{R_1}\right) + \dfrac{v_{s2}R_4 + v_o R_3}{R_3 + R_4}\left(1 + \dfrac{R_2}{R_1}\right) \\ v_o = v_A \dfrac{R_6}{R_5 + R_6} \end{array}\right\} \Rightarrow v_o\left[\left(1 + \dfrac{R_5}{R_6}\right) - \dfrac{1 + \dfrac{R_2}{R_1}}{1 + \dfrac{R_4}{R_3}}\right]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

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

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

2.2.13. Convertoarele logaritmic si anti-logaritmic





Convertorul logaritmic

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

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

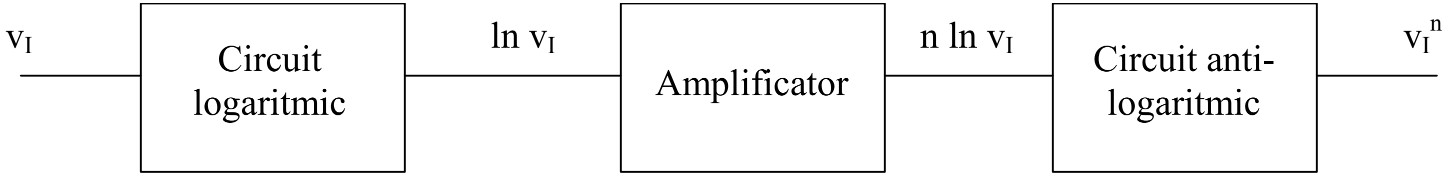
Convertorul anti-logaritmic

$$v_o = -iR$$

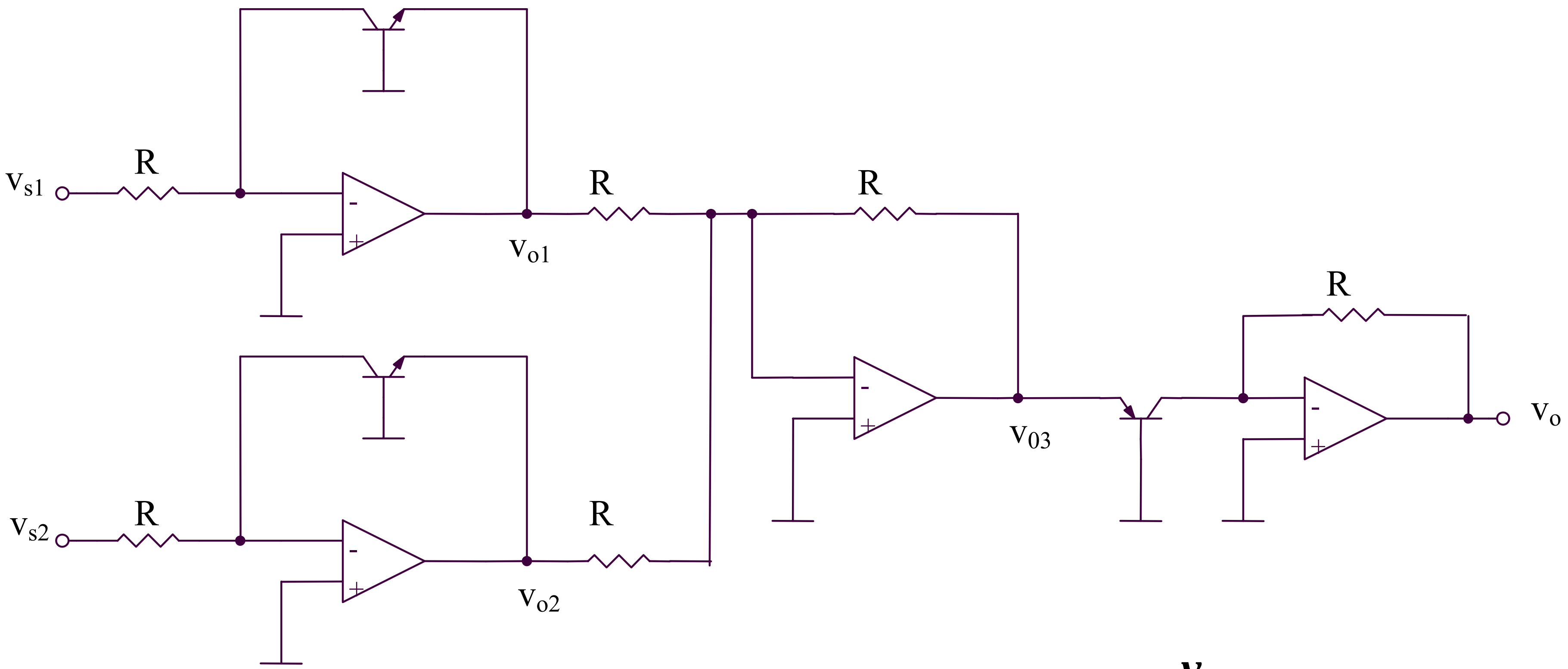
$$i = I_S e^{\frac{v_{EB}}{V_{th}}} = I_S e^{\frac{v_S}{V_{th}}}$$

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

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



2.2.15. Circuit de multiplicare

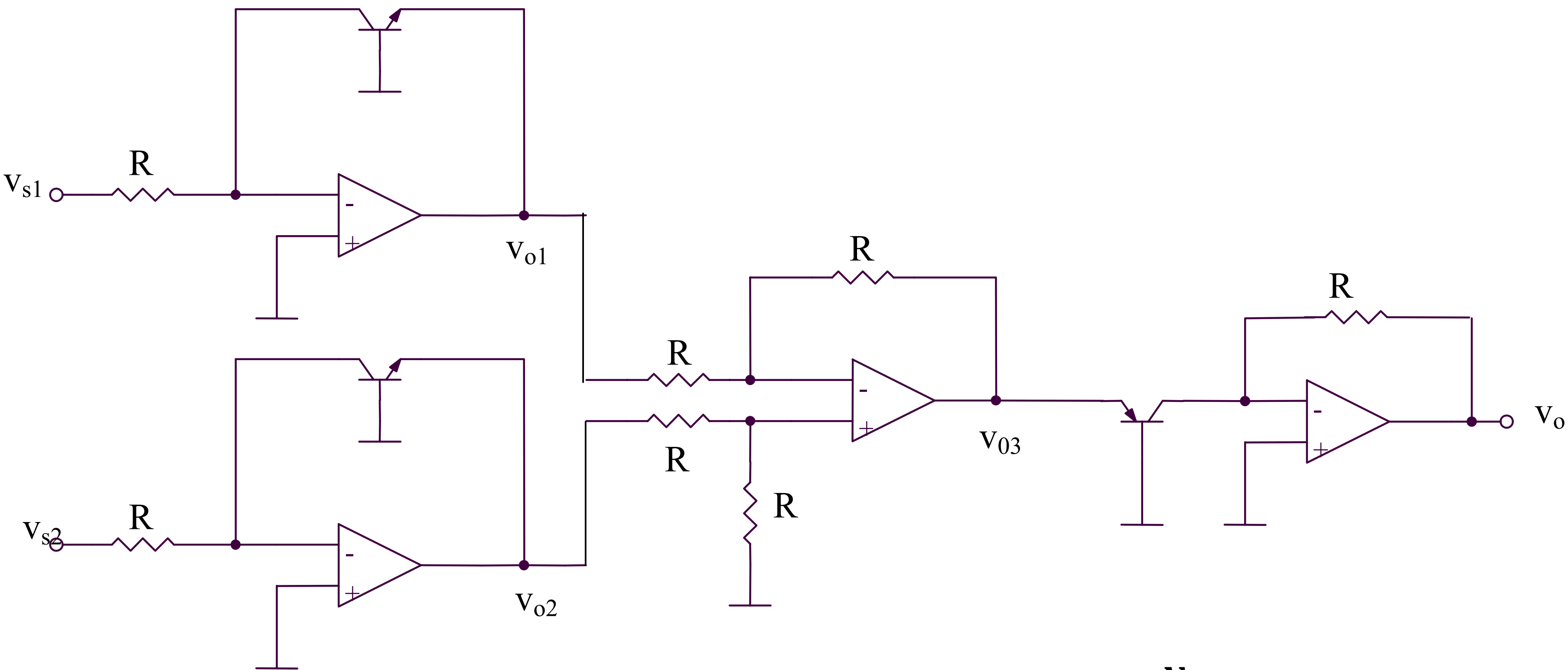


$$v_{o1} = -V_{th} \ln \frac{v_{s1}}{RI_S} \qquad v_{o2} = -V_{th} \ln \frac{v_{s2}}{RI_S}$$

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

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

2.2.16. Circuit de impartire

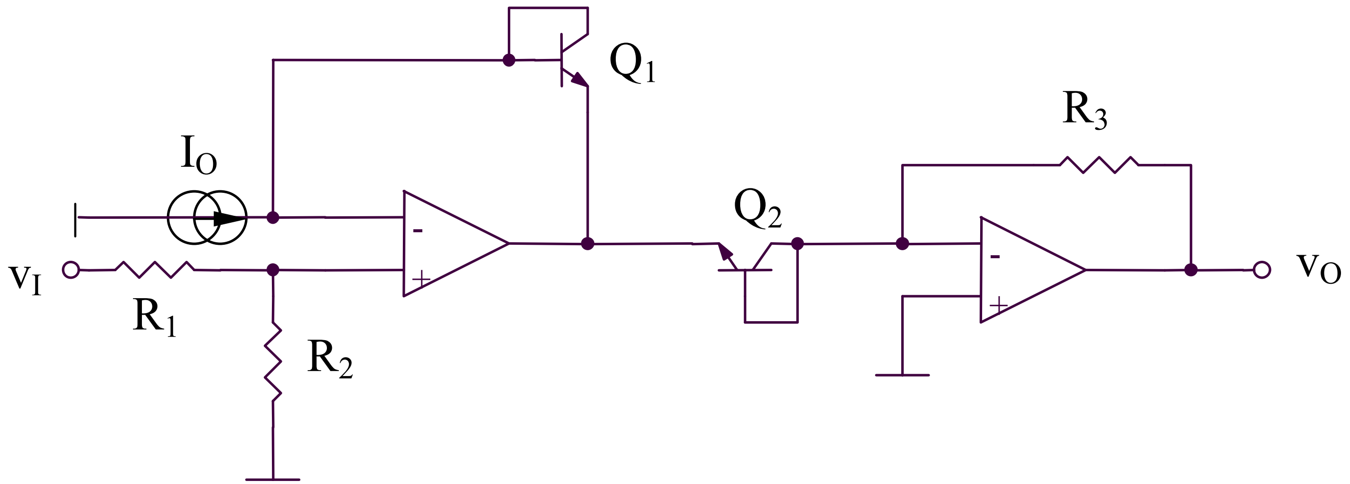


$$v_{o1} = -V_{th} \ln \frac{v_{s1}}{RI_S} \qquad v_{o2} = -V_{th} \ln \frac{v_{s2}}{RI_S}$$

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

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

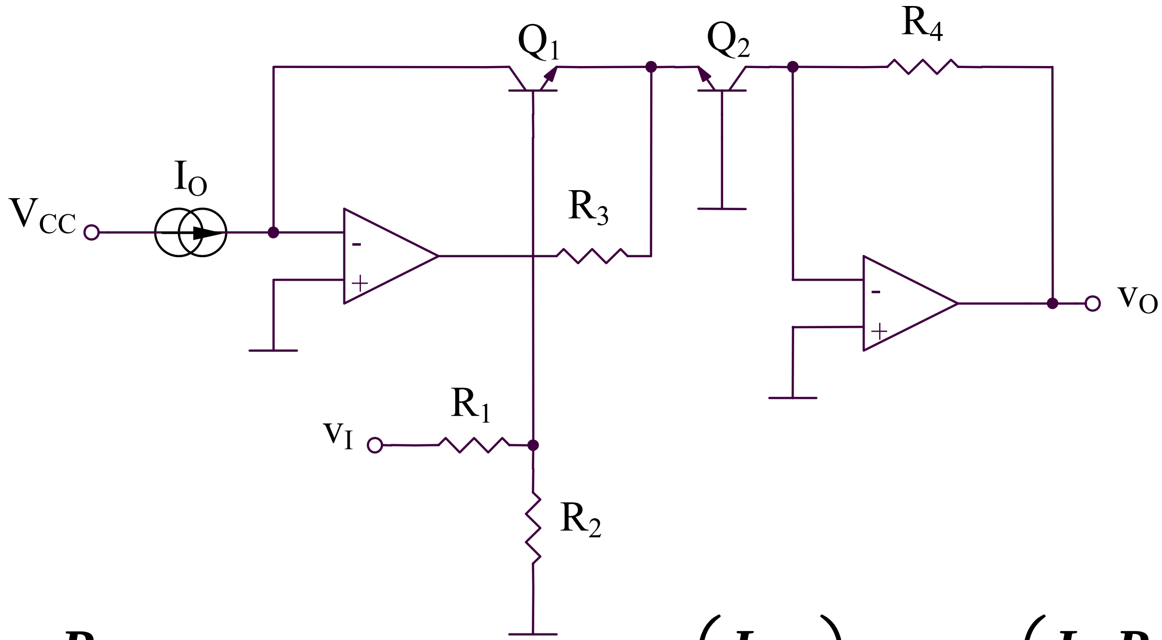
2.2.17. Circuit de exponentiere (1)



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

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

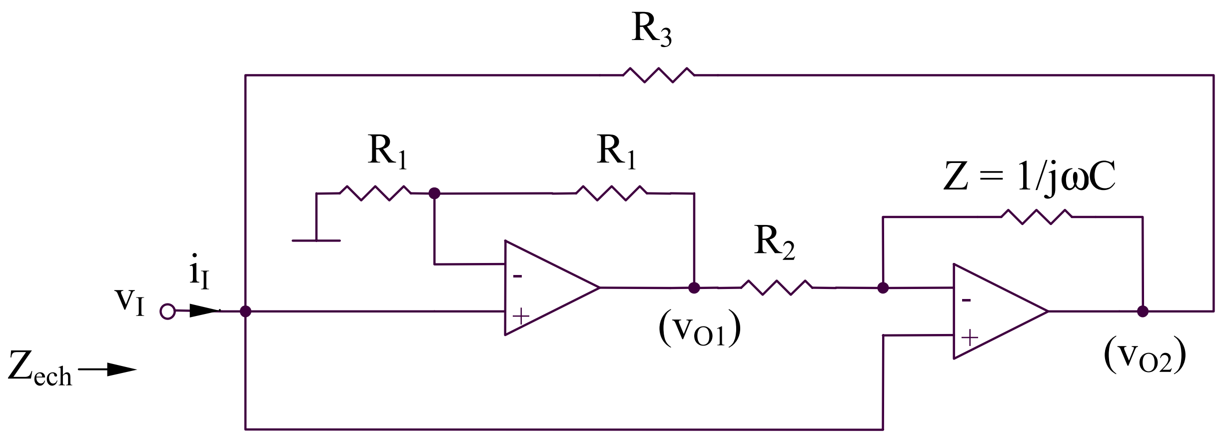
2.2.18. Circuit de exponentiere (2)



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

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

2.2.19. Simulator de impedanta



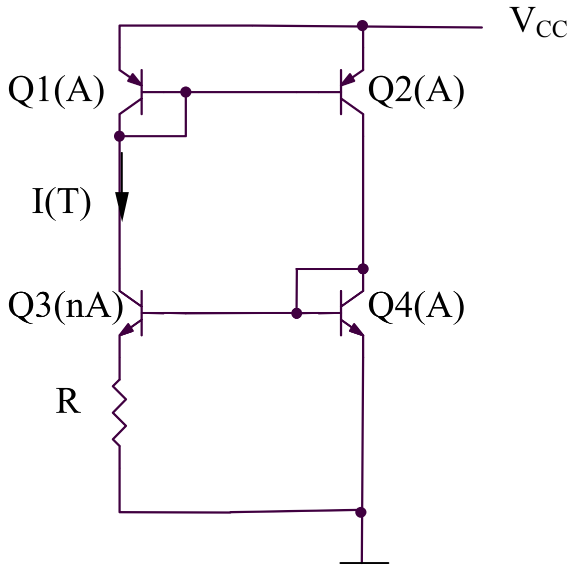
$$\left.\begin{aligned} v_{O2} &= v_I\left(1+\frac{Z}{R_2}\right)+v_{O1}\left(-\frac{Z}{R_2}\right) \\ v_{O1} &= 2v_I \end{aligned}\right\} \Rightarrow v_{O2} = v_I\left(1-\frac{Z}{R_2}\right)$$

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

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

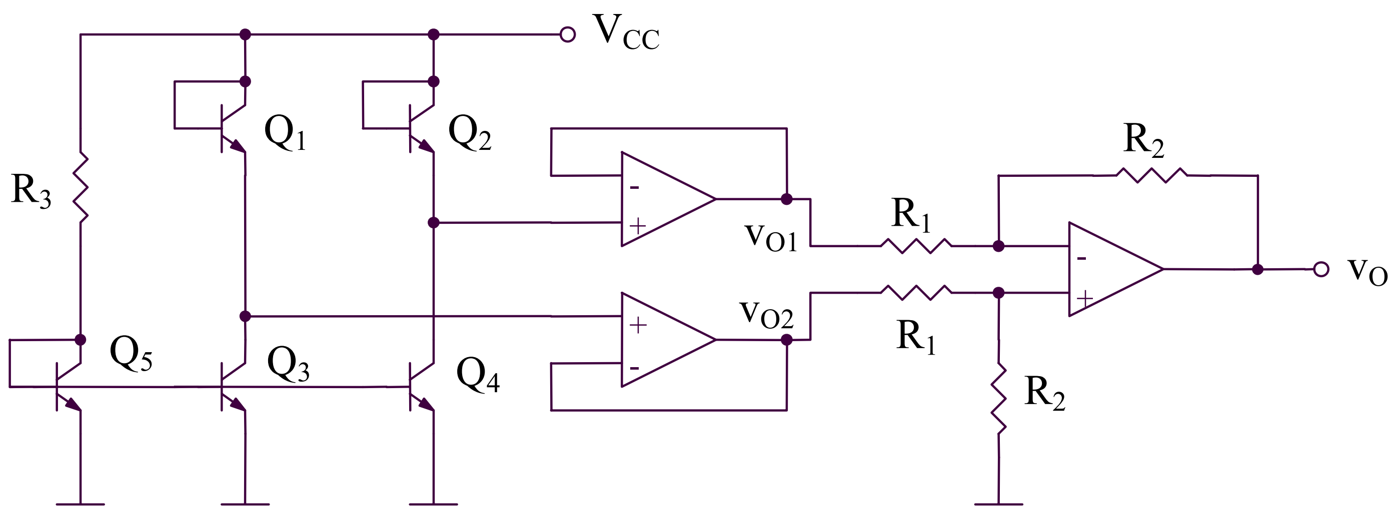
$$L_{ech} = R_2 R_3 C$$

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)

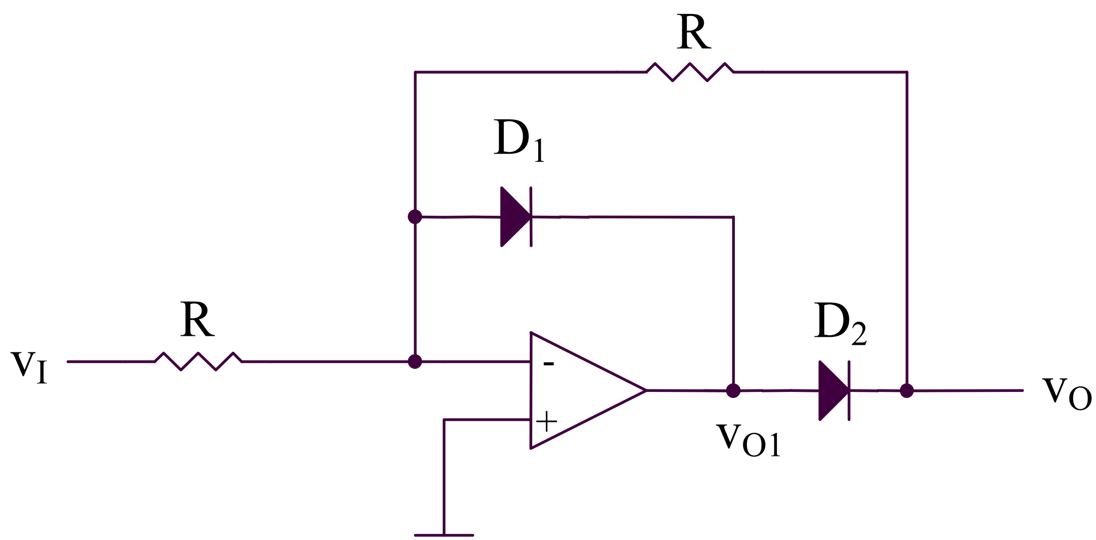


$$v_O = \frac{R_2}{R_1}(v_{O2} - v_{O1}) = \frac{R_2}{R_1}(v_{BE2} - v_{BE1}) = \frac{R_2}{R_1} V_{th} \ln\left(\frac{I_{C2}}{I_{C1}} \frac{I_{S1}}{I_{S2}}\right) \Rightarrow$$

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

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

2.2.22. Redresor mono-alternanta

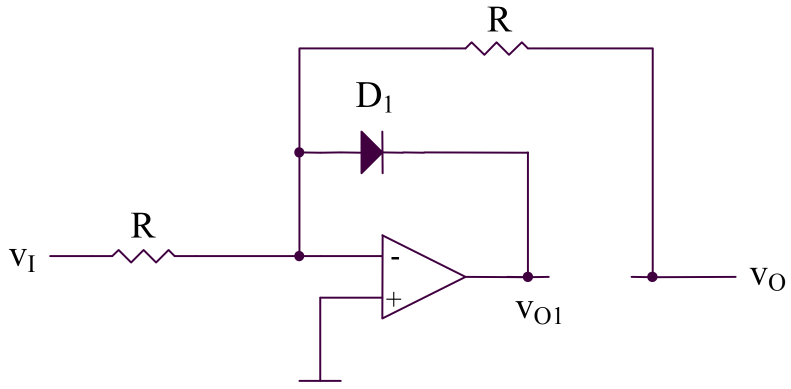


$$v_I > 0 \Rightarrow v_{O1} < 0 \Rightarrow D_1\,deschisa, D_2\,blocata$$

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

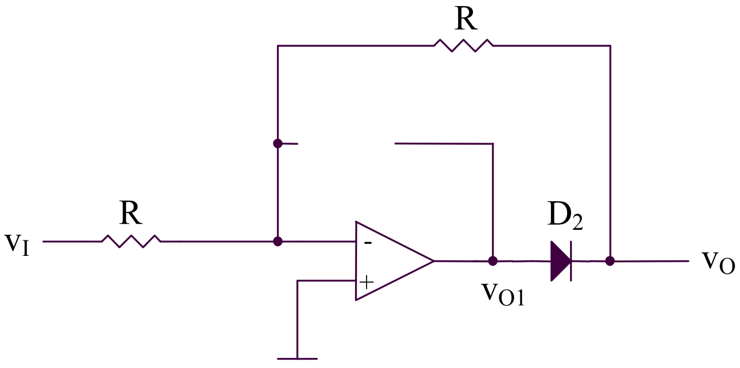
2.2.22. Redresor mono-alternanta

$$v_I > 0$$



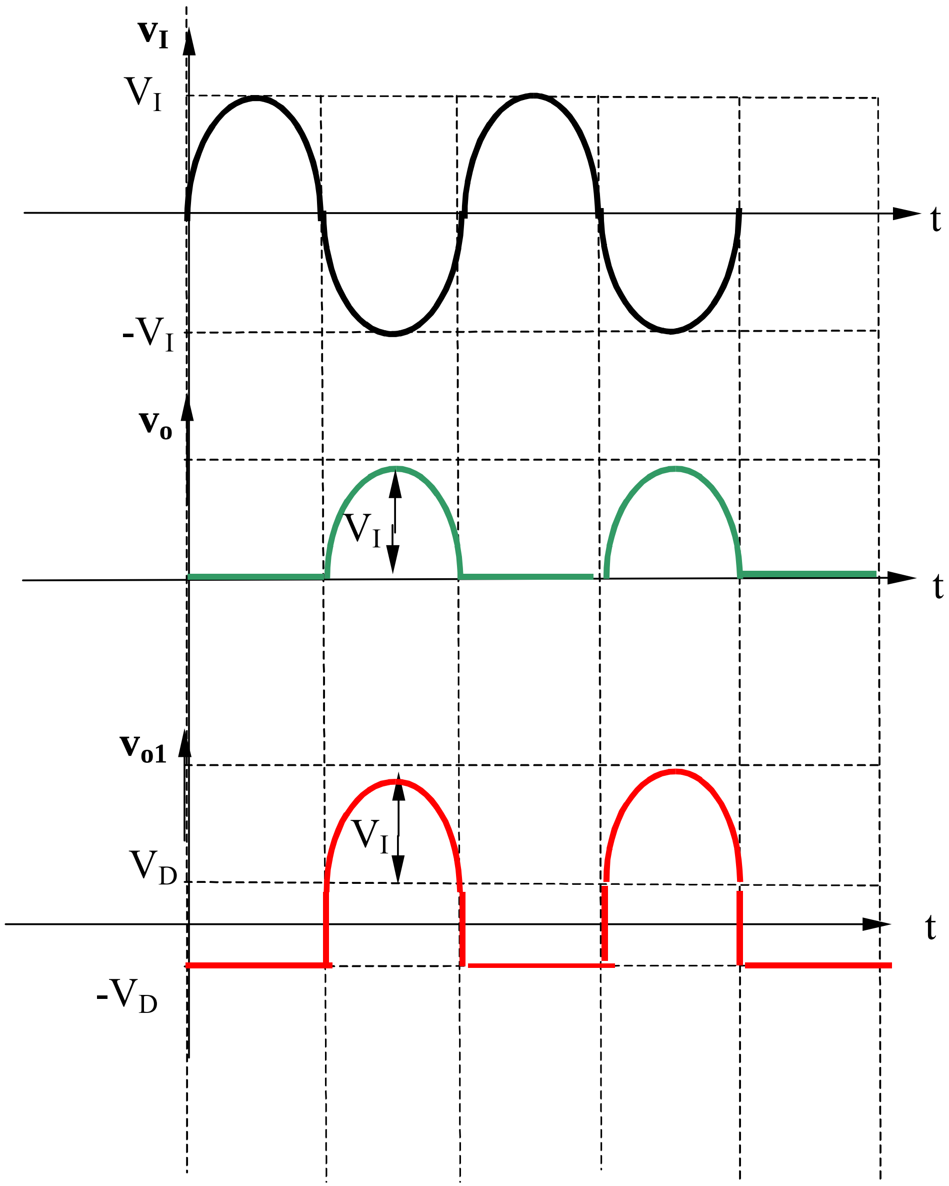
$$v_O = 0$$

$$v_I < 0$$



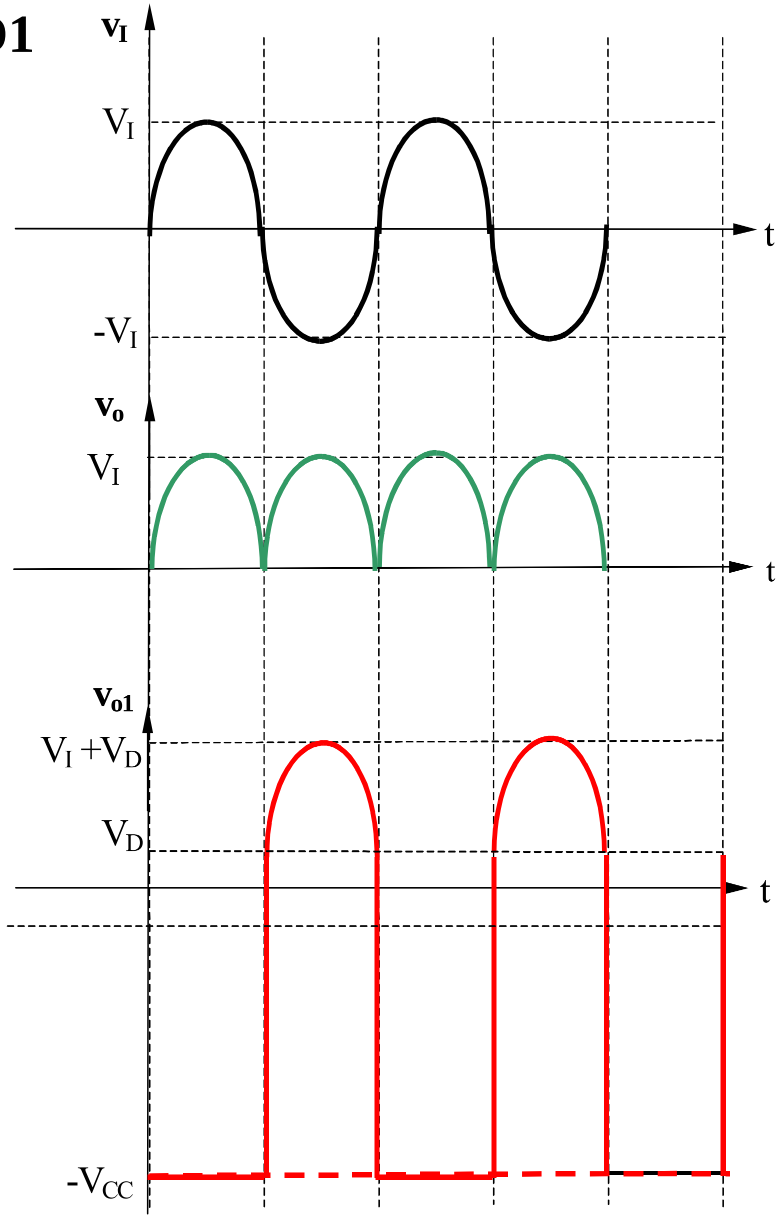
$$v_O = -\frac{R}{R} v_I = -v_I$$

2.2.22. Redresor mono-alternanta



2.2.22. Redresor mono-alternanta

Fara D1



Exemplu

f=10kHz

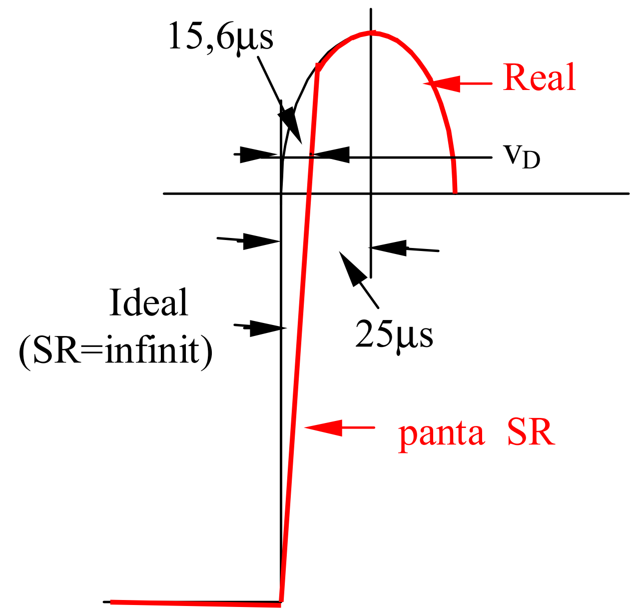
T=1/f=100 μs

T/2=50 μs

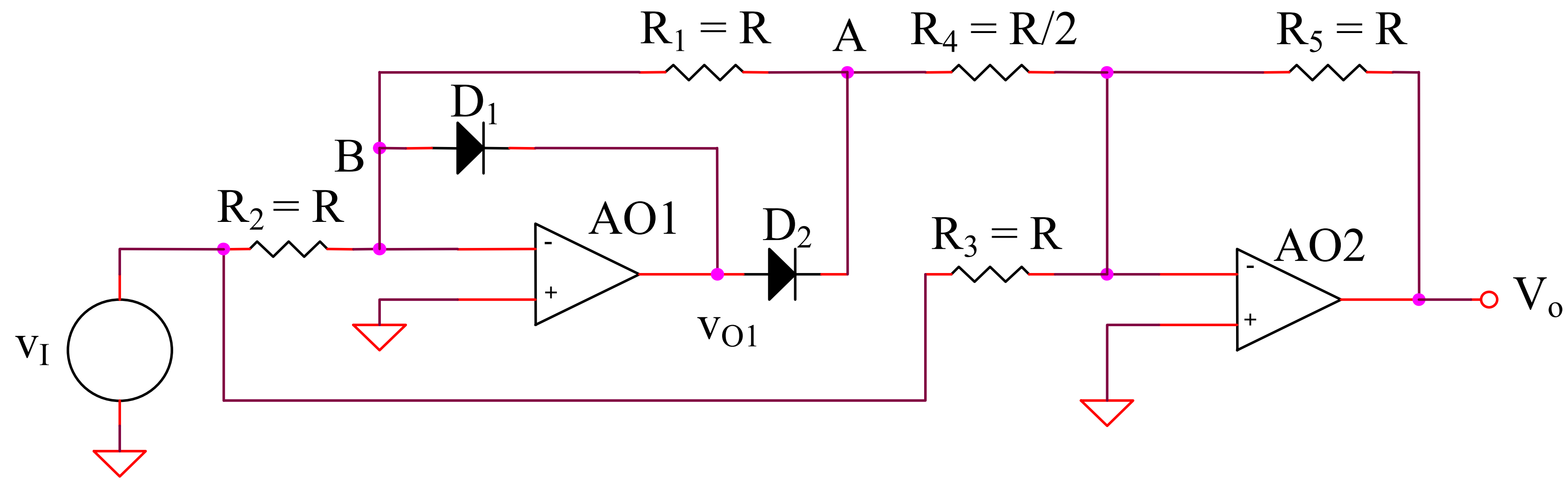
SR= 1V/μs

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

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



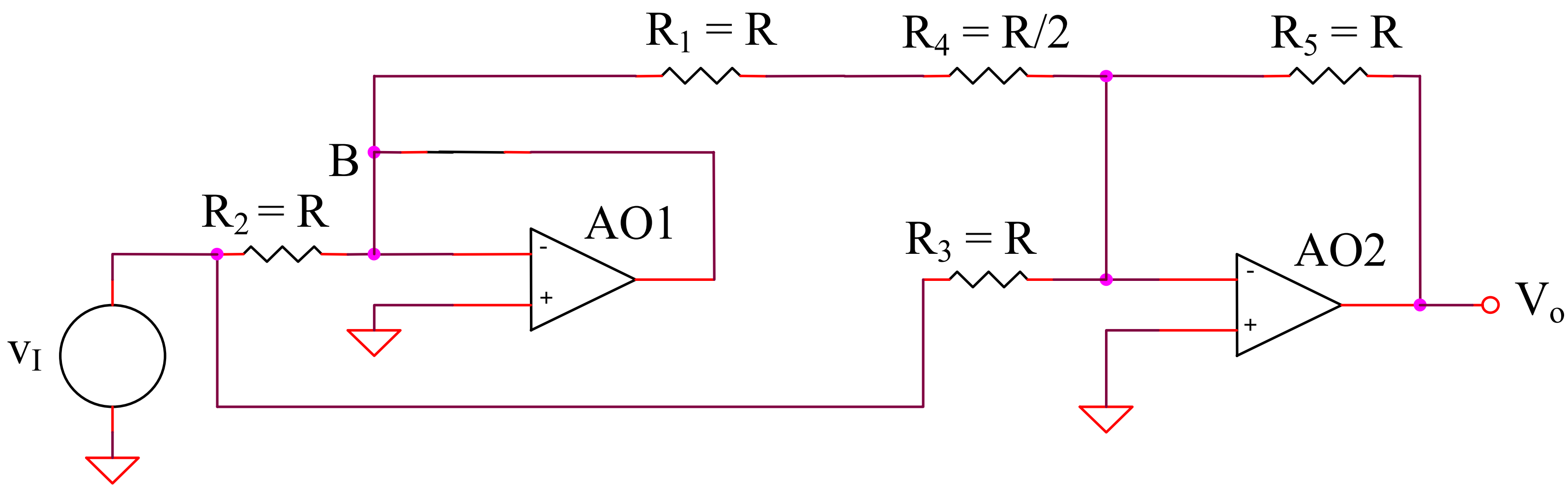
2.2.23. Redresor bi-alternanta (1)



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

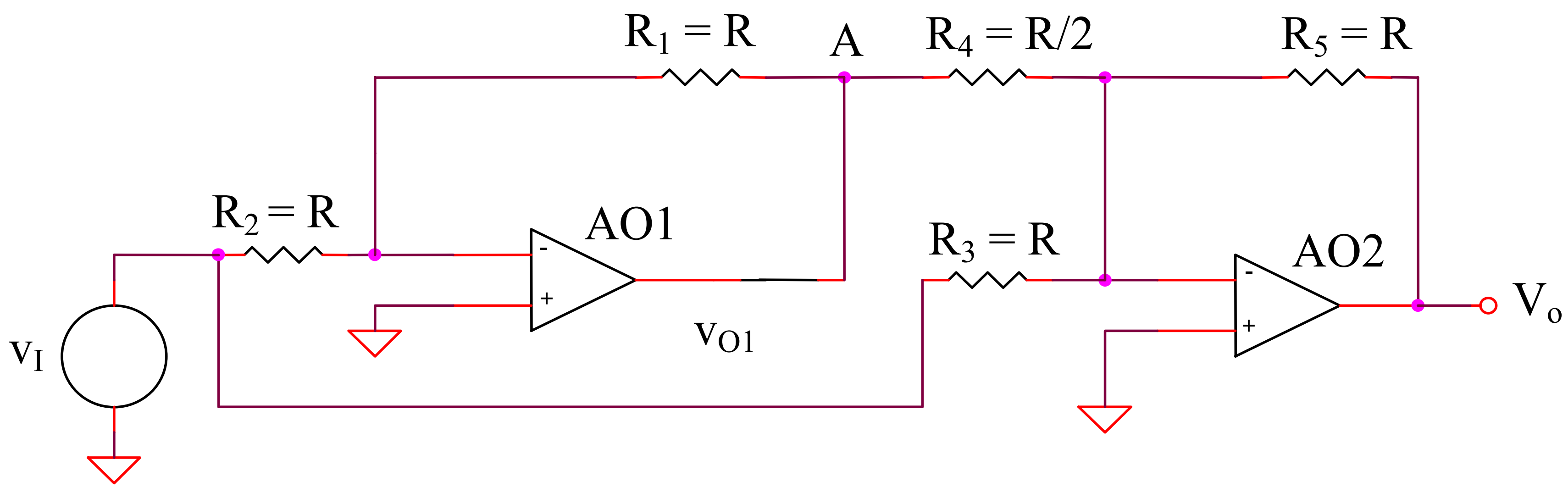
$$v_I < 0 \Rightarrow v_{O1} > 0 \Rightarrow D_2 \, deschisa, D_1 \, blocata$$

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)



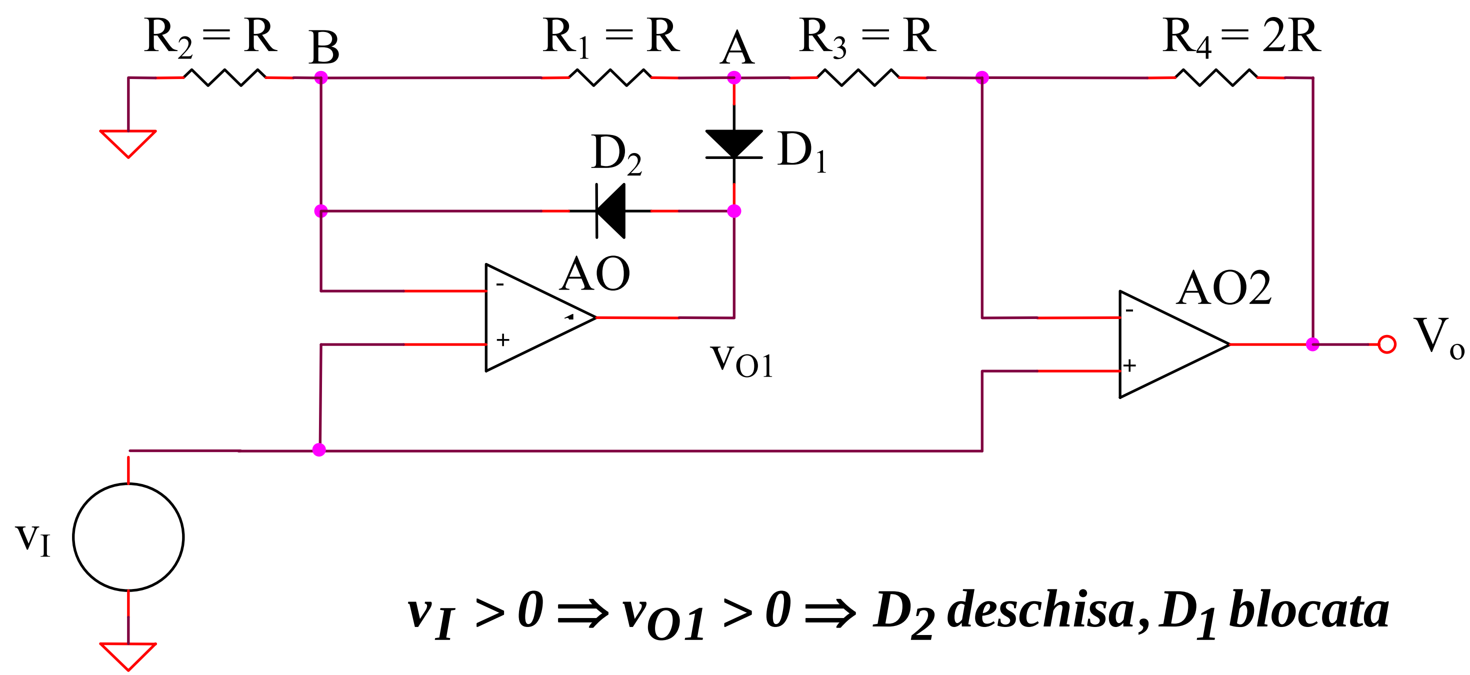
$v_I < 0$

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

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

Concluzie: $v_O = -|v_I|$

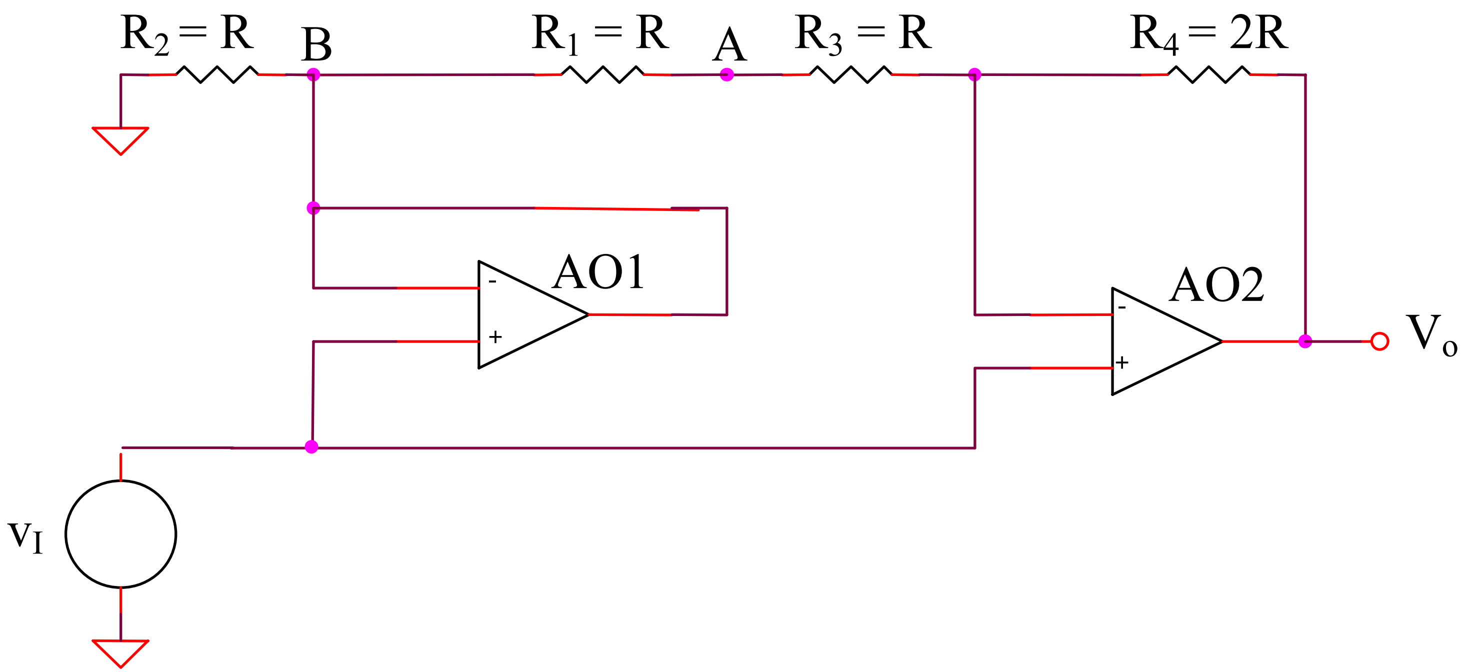
2.2.24. Redresor bi-alternanta (2)



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

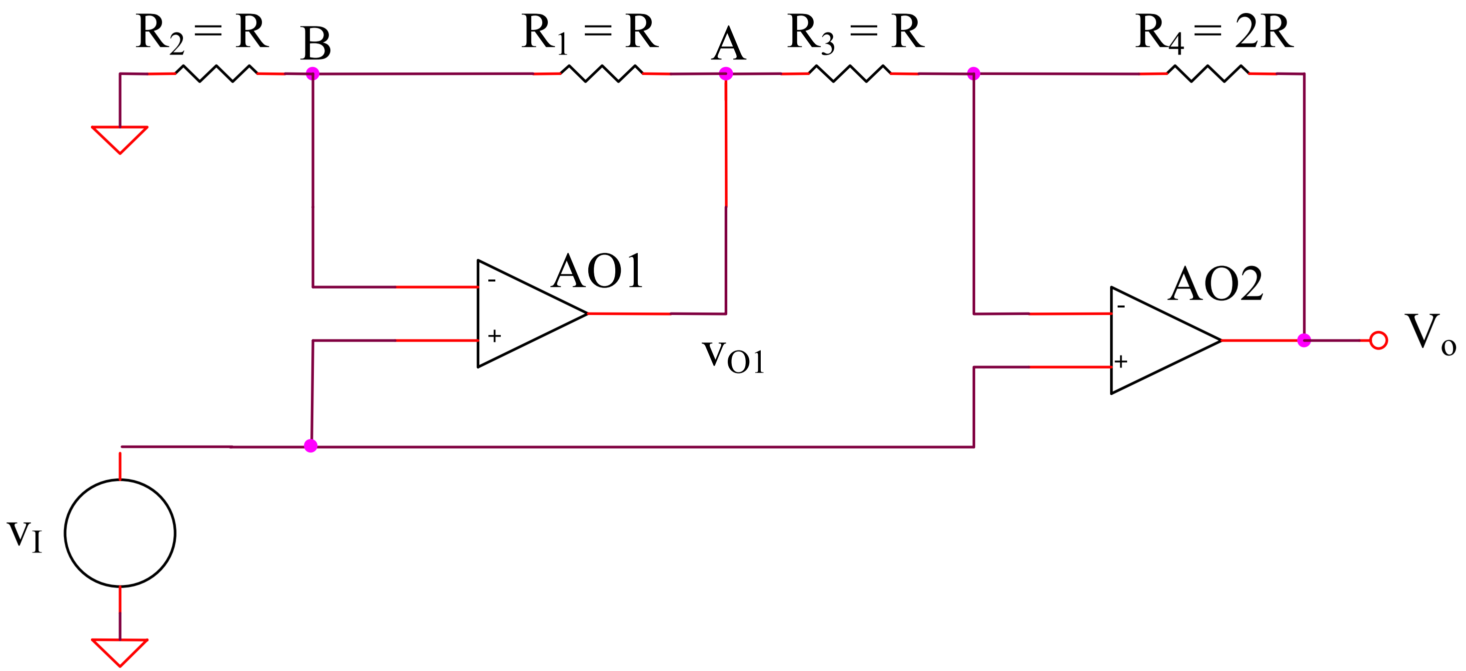
$$v_I < 0 \Rightarrow v_{O1} < 0 \Rightarrow D_1\ deschisa, D_2\ blocata$$

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)



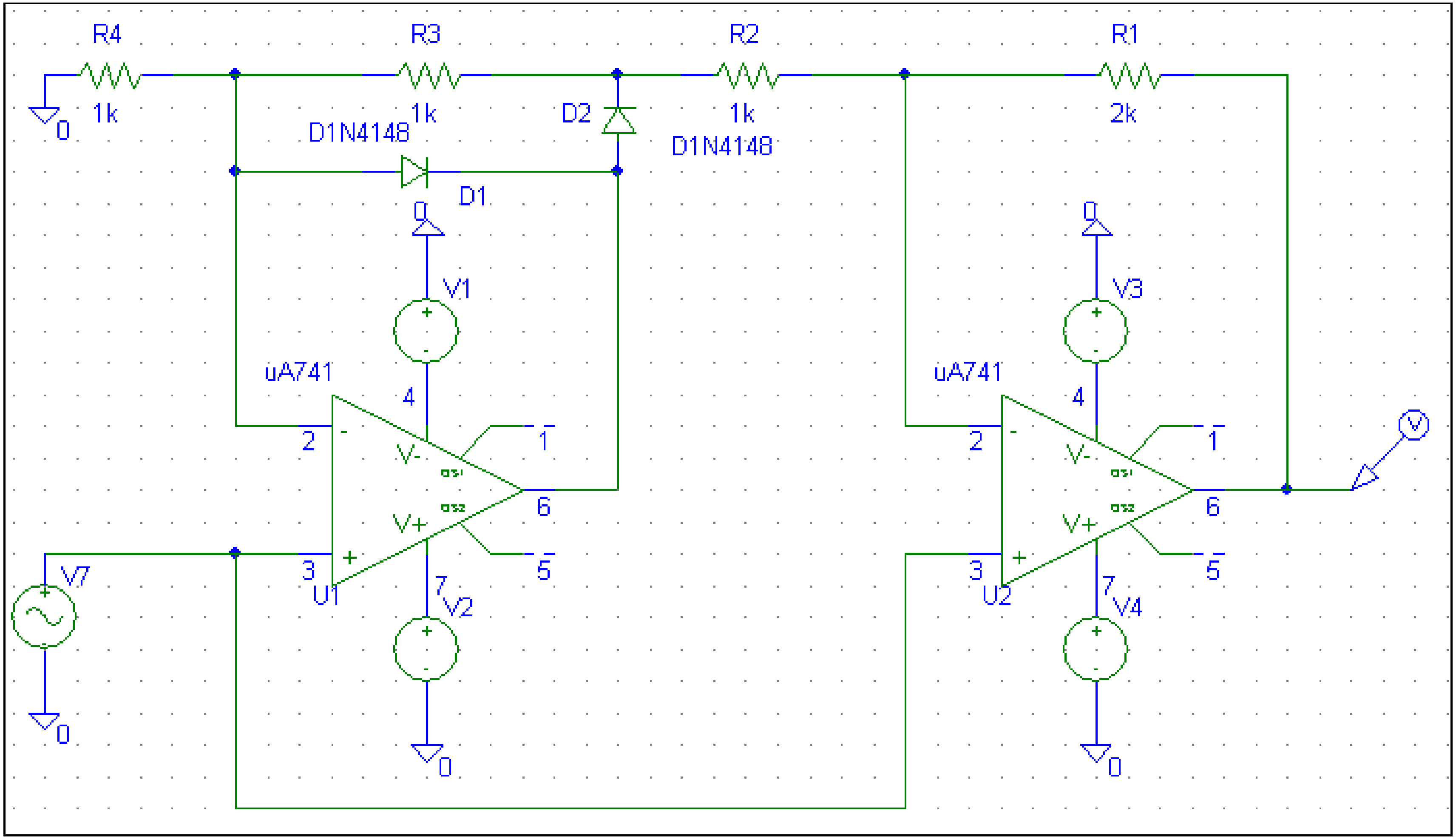
$$v_I < 0 \qquad V_A = \left(1 + \frac{R_1}{R_2}\right) v_I = 2v_I \qquad v_O = \left(1 + \frac{R_4}{R_3}\right) v_I - \frac{R_4}{R_3} V_A = -v_I$$

Concluzie: $v_O = |v_I|$

SIMULARI pentru redresorul bialternanta (2)

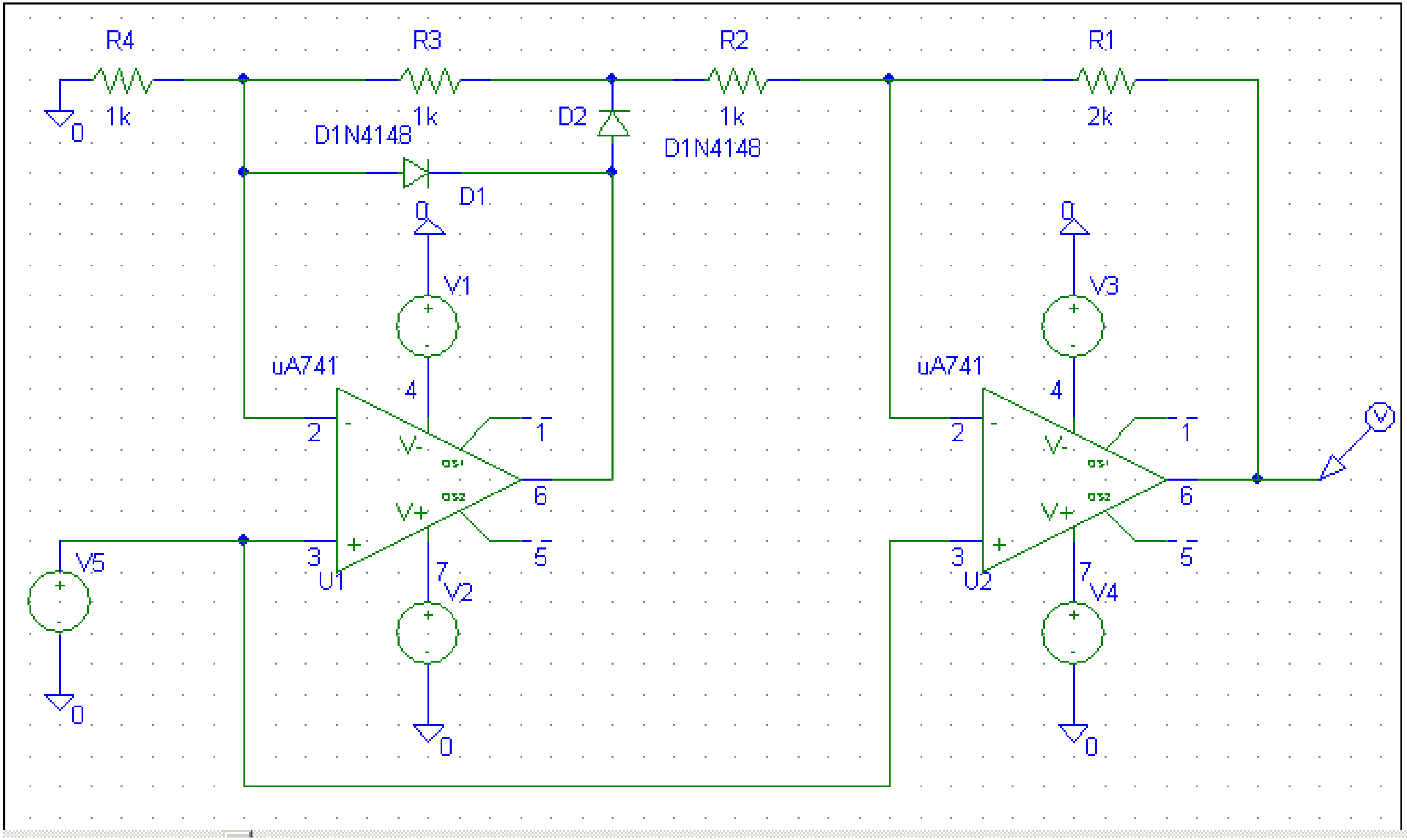
SIMULARI pentru redresorul bialternanta (2)

SIM 2.9: V_O (t)

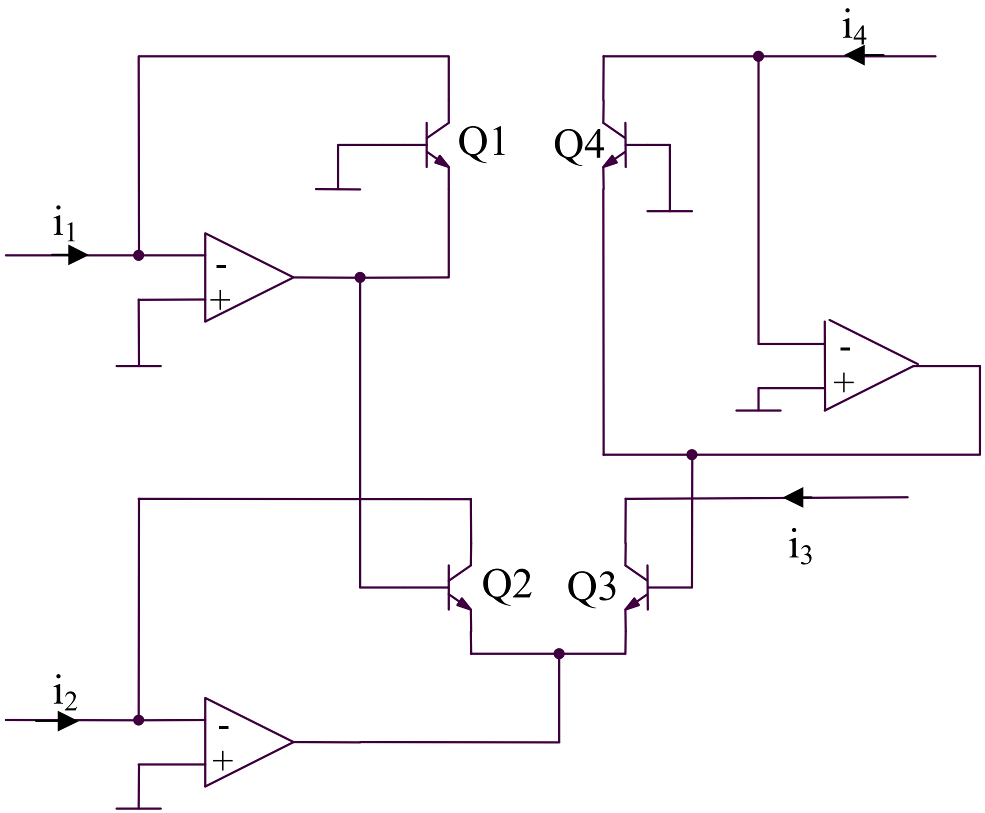


SIMULARI pentru redresorul bialternanta (2)

SIM 2.10: V_O (V_5)



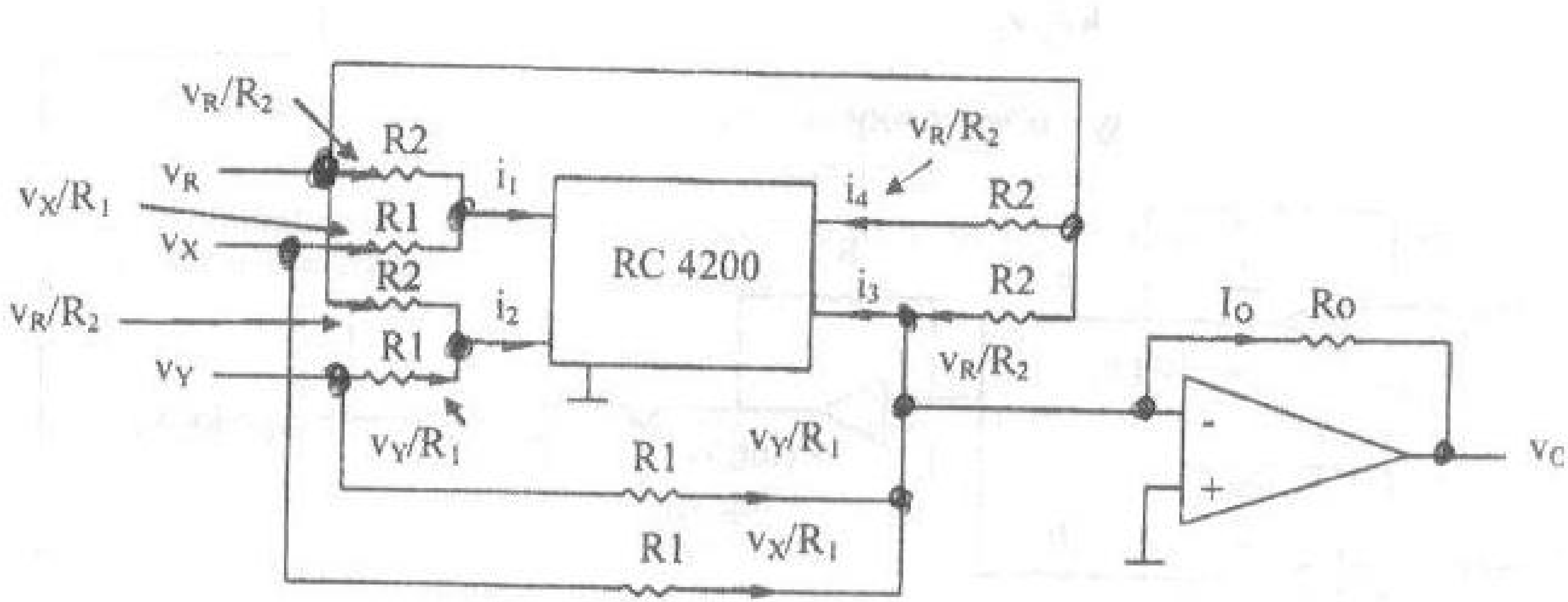
2.2.25. Circuit multifunctional RC 4200



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

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

2.2.25. Circuit multifunctional RC 4200 - aplicatie

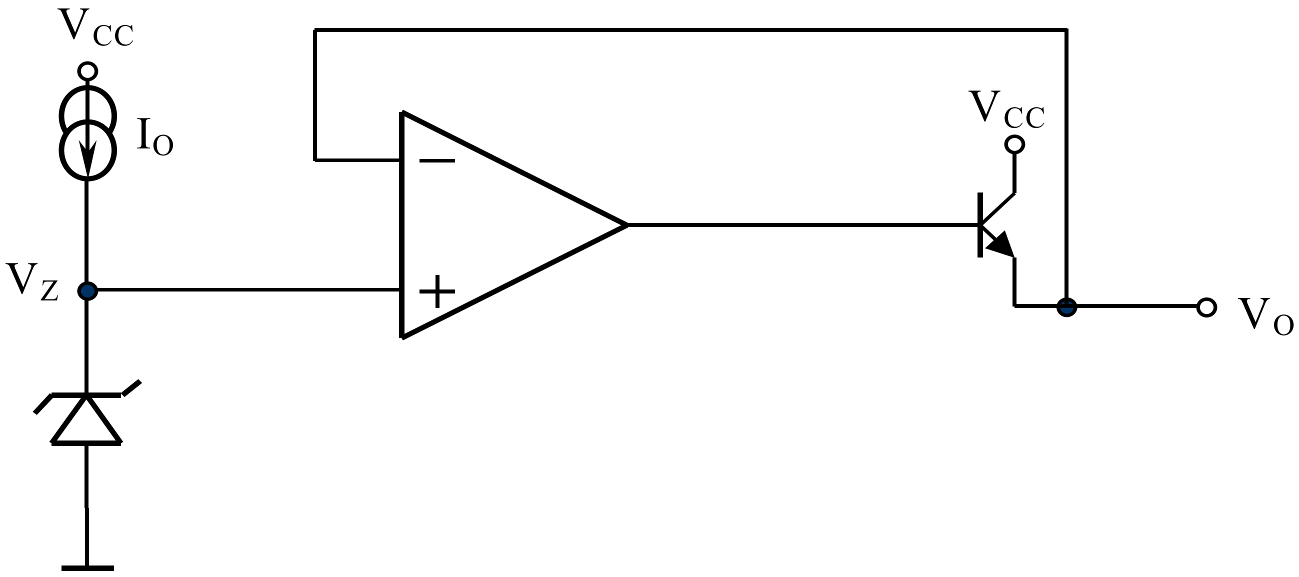


$$i_3 = \frac{i_1 i_2}{i_4} = \frac{R_2}{V_R}\left(\frac{V_R}{R_2} + \frac{V_X}{R_1}\right)\left(\frac{V_R}{R_2} + \frac{V_Y}{R_1}\right) = \frac{V_R}{R_2} + \frac{V_X}{R_1} + \frac{V_Y}{R_1} + \frac{R_2 V_X V_Y}{V_R R_1^2}$$

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

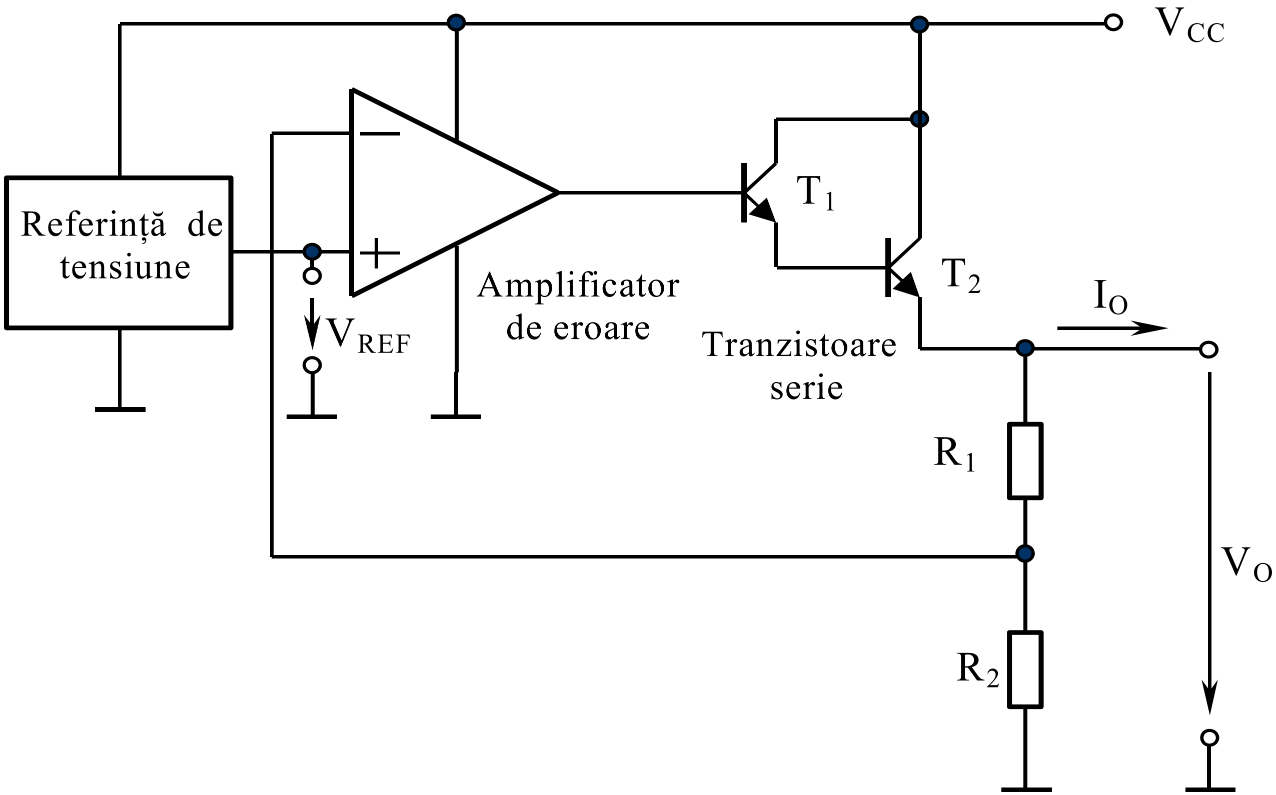
$$v_O = -i_O R_O = \frac{R_2 R_O}{V_R R_1^2} V_X V_Y$$

<u>2.2.26. Stabilizator de tensiune (1)</u>



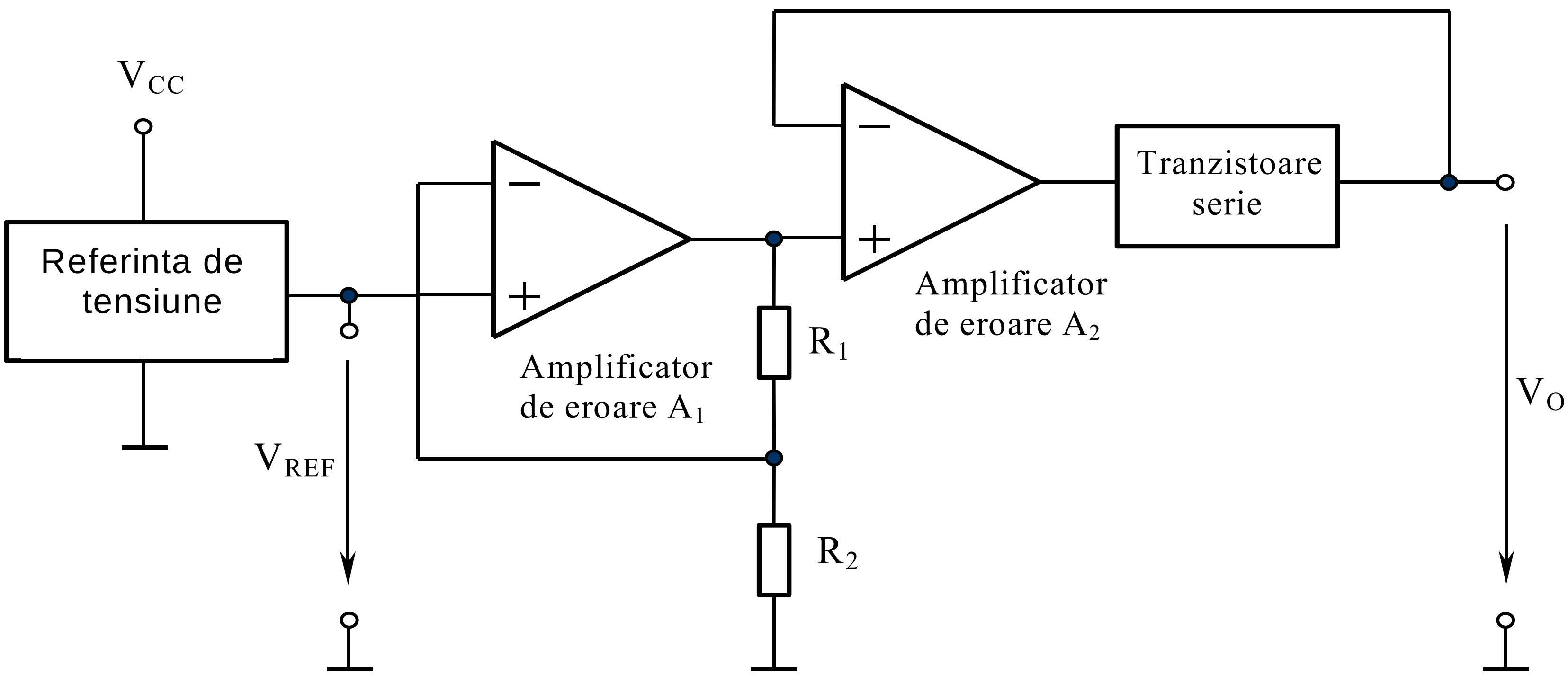
$$V_O = V_Z$$

2.2.27. Stabilizator de tensiune (2)



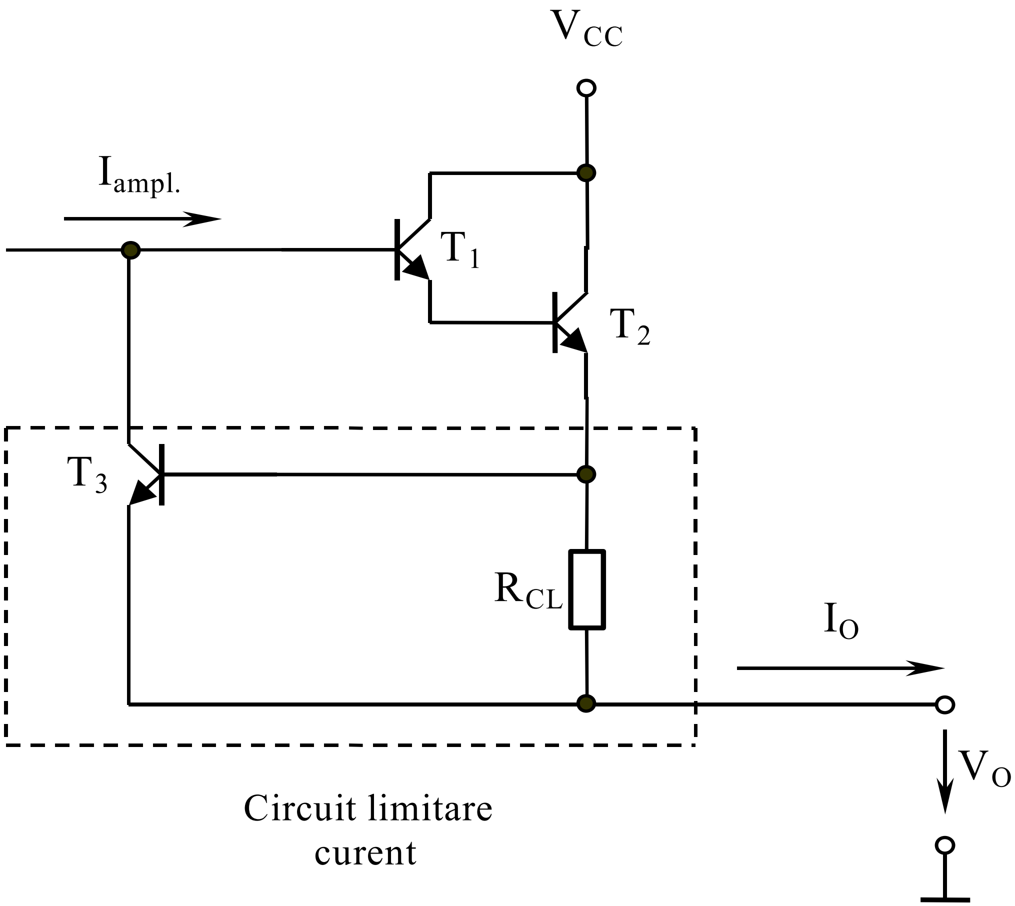
$$V_O \frac{R_2}{R_1 + R_2} = V_{REF} \Rightarrow V_O = V_{REF}\left(1 + \frac{R_1}{R_2}\right)$$

2.2.28. Stabilizator de tensiune (3)



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

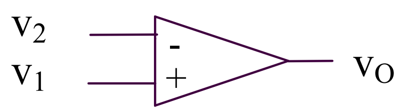
2.2.29. Circuit de protectie la supracurent



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

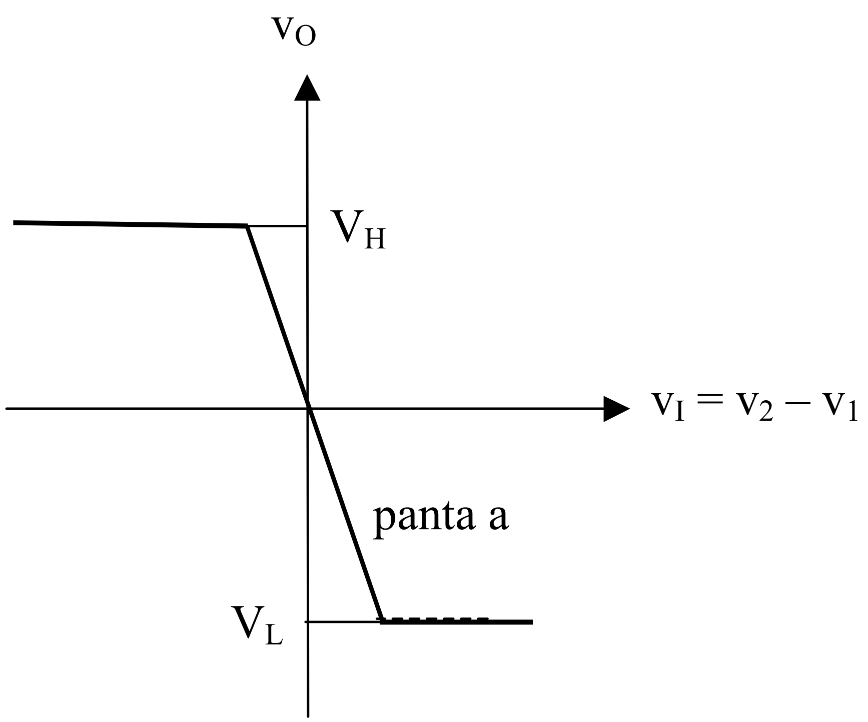
2.3. Comparatoare

2.3.1. Comparator simplu

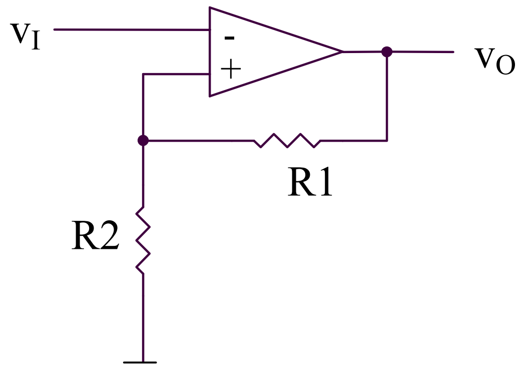


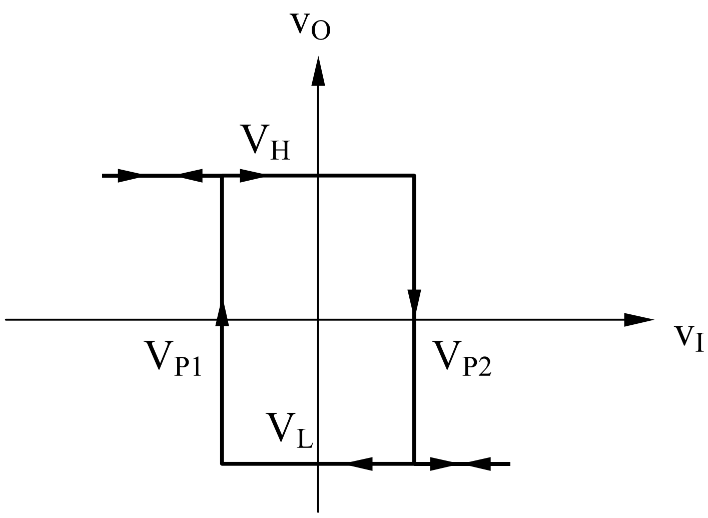
$$v_1 > v_2 \Rightarrow v_O = V_H$$

$$v_1 < v_2 \Rightarrow v_O = V_L$$



2.3.2. Comparator cu histerezis





$$V_{P1} = V_L \frac{R_2}{R_1 + R_2}$$

$$V_{P2} = V_H \frac{R_2}{R_1 + R_2}$$