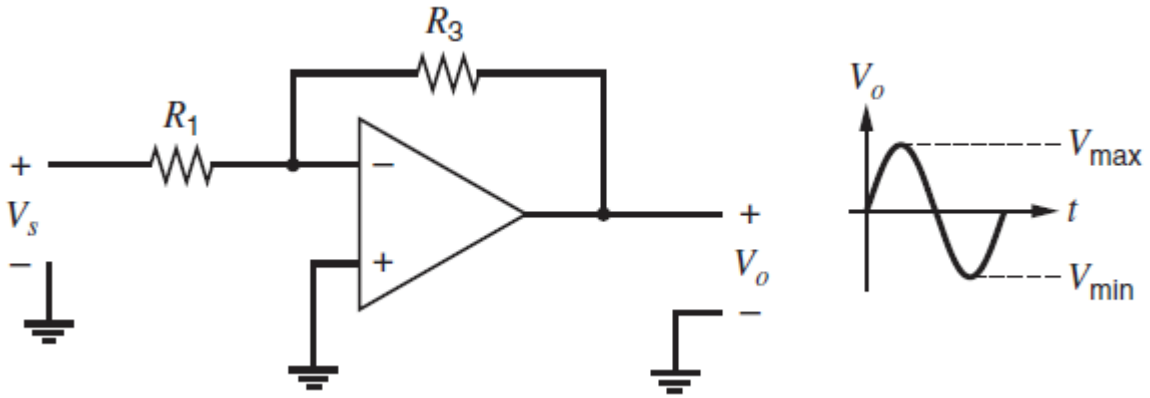
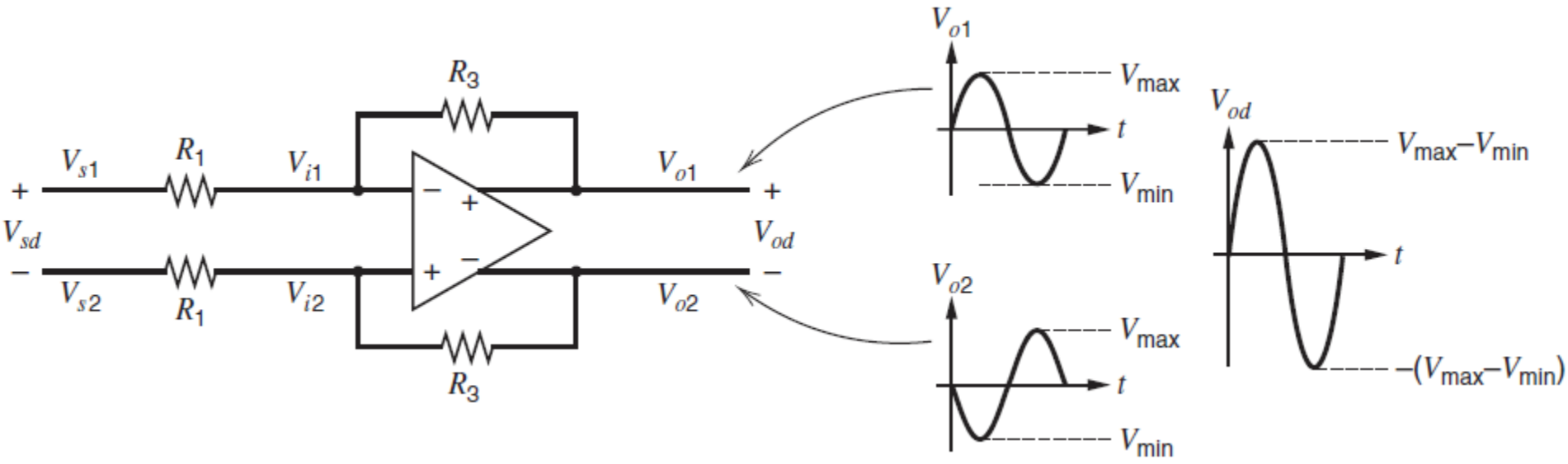
Osnovi analogne elektronike
IV semestar

KOLA SA OPERACIONIM POJAČAVAČIMA I NEGATIVNOM POVRATNOM SPREGOM

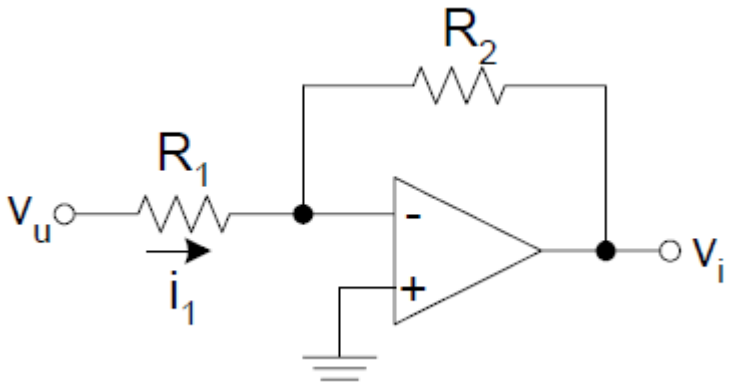
Operacioni pojačavač sa jednostrukim izlazom



Operacioni pojačavač sa diferencijalnim izlazom



Invertujući pojačavač sa beskonačnim pojačanjem

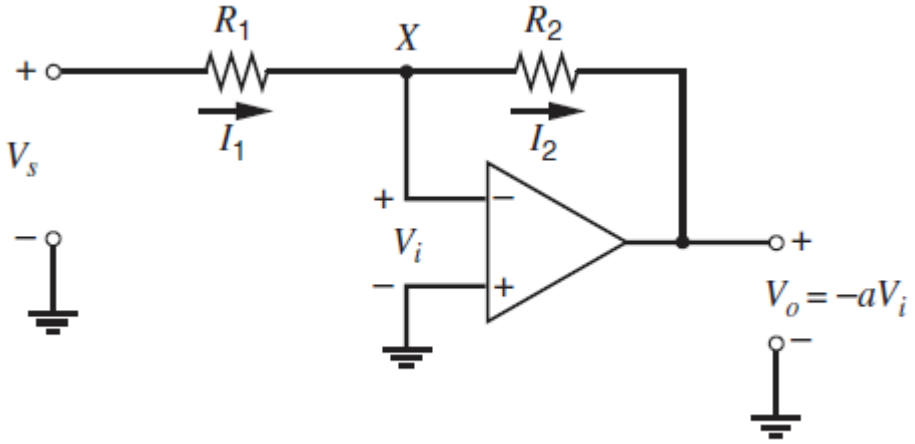


$$i_1 = \frac{v_u}{R_1}$$

$$v_i = -R_2 i_1 = -\frac{R_2}{R_1} v_u$$

$$A_v = \frac{v_i}{v_u} = -\frac{R_2}{R_1}$$

Invertujući pojačavač sa konačnim pojačanjem



$$\frac{V_s - V_i}{R_1} + \frac{V_o - V_i}{R_2} = 0$$

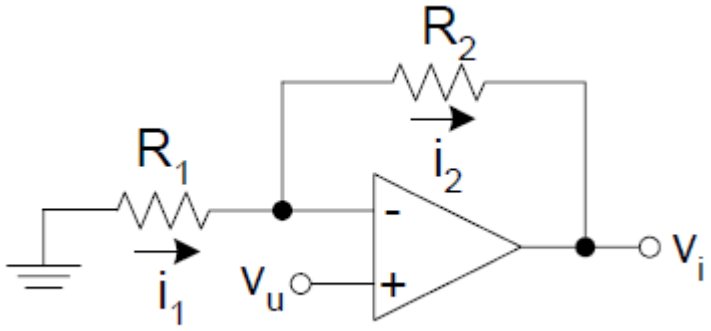
$$V_i = \frac{-V_o}{a}$$

$$\frac{V_o}{V_s} = -\frac{R_2}{R_1}\left[\frac{1}{1 + \frac{1}{a}\left(1 + \frac{R_2}{R_1}\right)}\right]$$

$$\frac{V_o}{V_s} \simeq -\frac{R_2}{R_1}$$

$$a\left(\frac{R_1}{R_1 + R_2}\right) \gg 1$$

Neinvertujući pojačavač sa beskonačnim pojačanjem

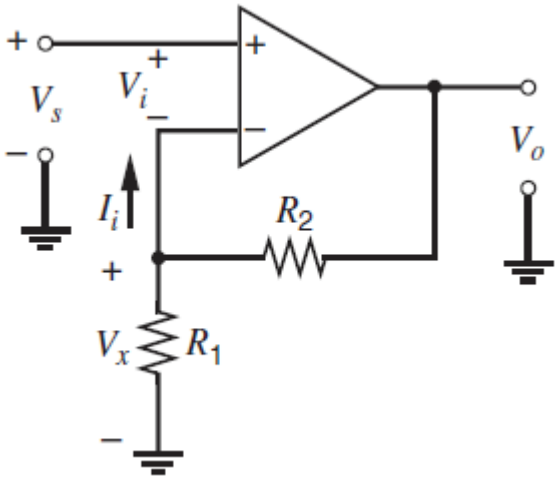


$$i_1 = \frac{v_u}{R_1}$$

$$i_2 = \frac{v_i - v_u}{R_2} = i_1 = \frac{v_u}{R_1}$$

$$A_v = \frac{v_i}{v_u} = \frac{R_1 + R_2}{R_1} = 1 + \frac{R_2}{R_1}$$

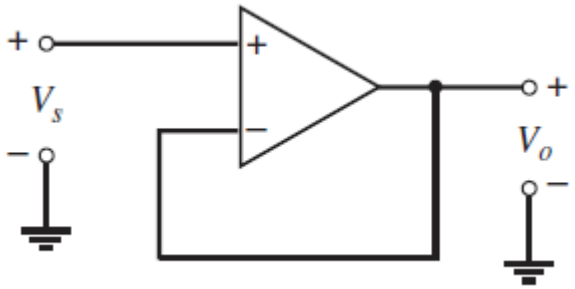
Neinvertujući pojačavač sa konačnim pojačanjem



$$V_x = V_o\left(\frac{R_1}{R_1 + R_2}\right) = V_s - \frac{V_o}{a}$$

$$\frac{V_o}{V_s} = \left(1 + \frac{R_2}{R_1}\right)\frac{\dfrac{aR_1}{R_1 + R_2}}{1 + \dfrac{aR_1}{R_1 + R_2}} \simeq \left(1 + \frac{R_2}{R_1}\right) \qquad a\left(\frac{R_1}{R_1 + R_2}\right) \gg 1$$

Jedinični bafer sa beskonačnim pojačanjem



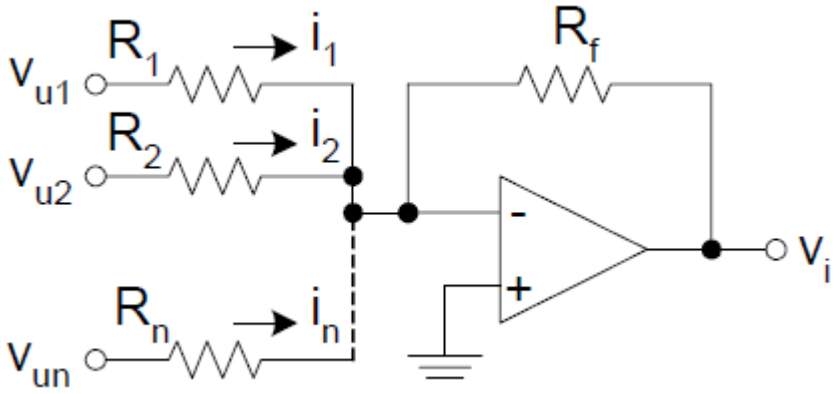
$$R_1 \to \infty$$

$$R_2 = 0$$

$$a \gg 1$$

$$\frac{V_o}{V_s} = 1$$

Sabirač



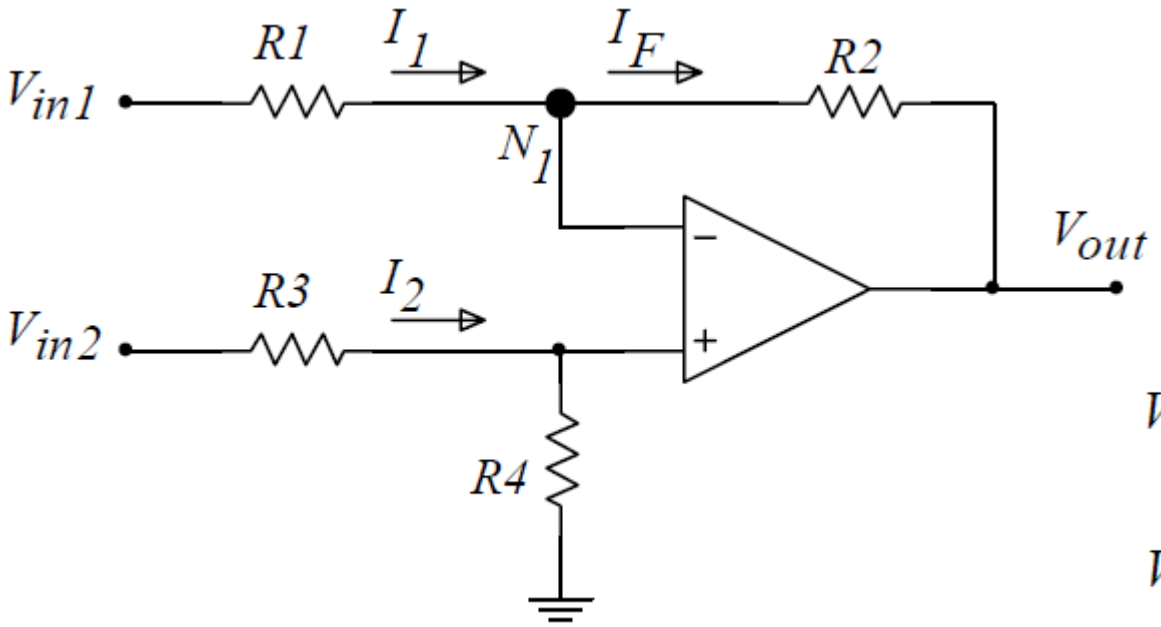
$$i_k = \frac{v_{uk}}{R_k},\ k = 1,2,\ldots,n$$

$$v_i = -R_f \sum_{k=1}^{n} i_k = -R_f \sum_{k=1}^{n} \frac{v_{uk}}{R_k}$$

Za identične ulazne otpornike: $R_1 = R_2 = \cdots = R_n = R$

$$v_i = -R_f \sum_{k=1}^{n} \frac{v_{uk}}{R_k} = -\frac{R_f}{R} \sum_{k=1}^{n} v_{uk}$$

Diferencijalni pojačavač



Izlazni napon se računa kao superpozicija dva napona:

$$V_{out1} = -V_{in1}\left(\frac{R2}{R1}\right)$$

$$V_{out2} = V_{in2}\left(\frac{R4}{R3+R4}\right)\left(1+\frac{R2}{R1}\right)$$

$$V_{out} = V_{out2} + V_{out1} = V_{in2}\left(\frac{R4}{R3+R4}\right)\left(1+\frac{R2}{R1}\right) - V_{in1}\frac{R2}{R1}$$

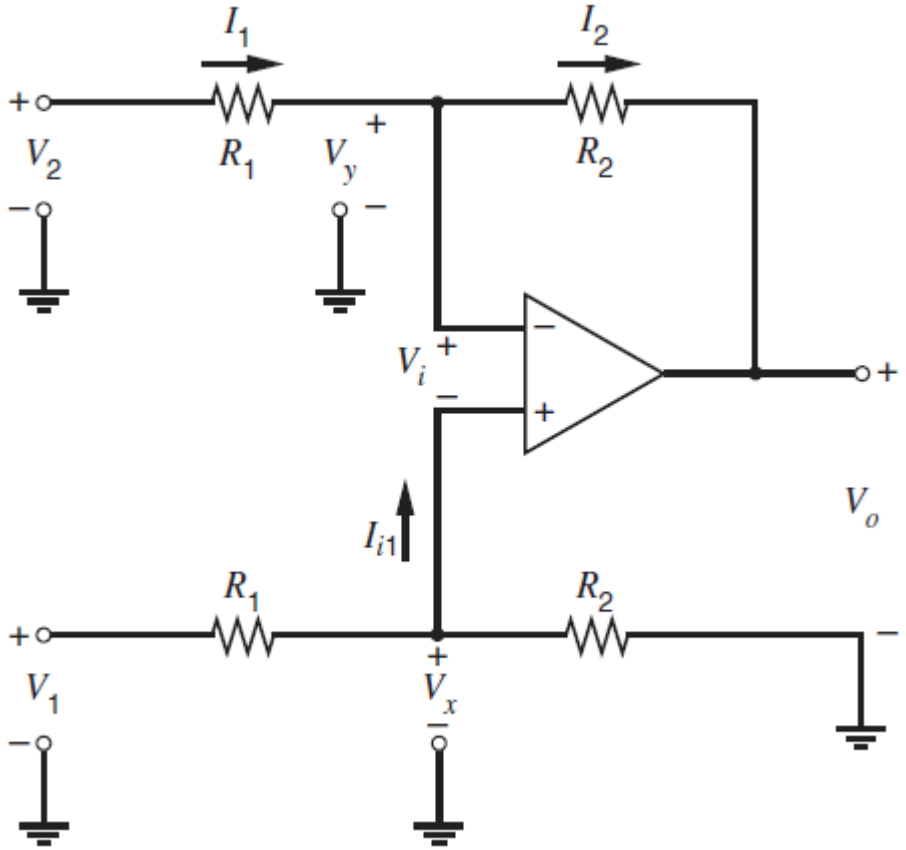
$$V_{out} = \frac{R2}{R1}\left(V_{in2} - V_{in1}\right)$$

Izlazni napon je proporcionalan razlici ulaznih napona ako je:

$$\left(\frac{R4}{R3+R4}\right)\left(1+\frac{R2}{R1}\right) = \frac{R2}{R1}$$

$$\frac{R4}{R3} = \frac{R2}{R1}$$

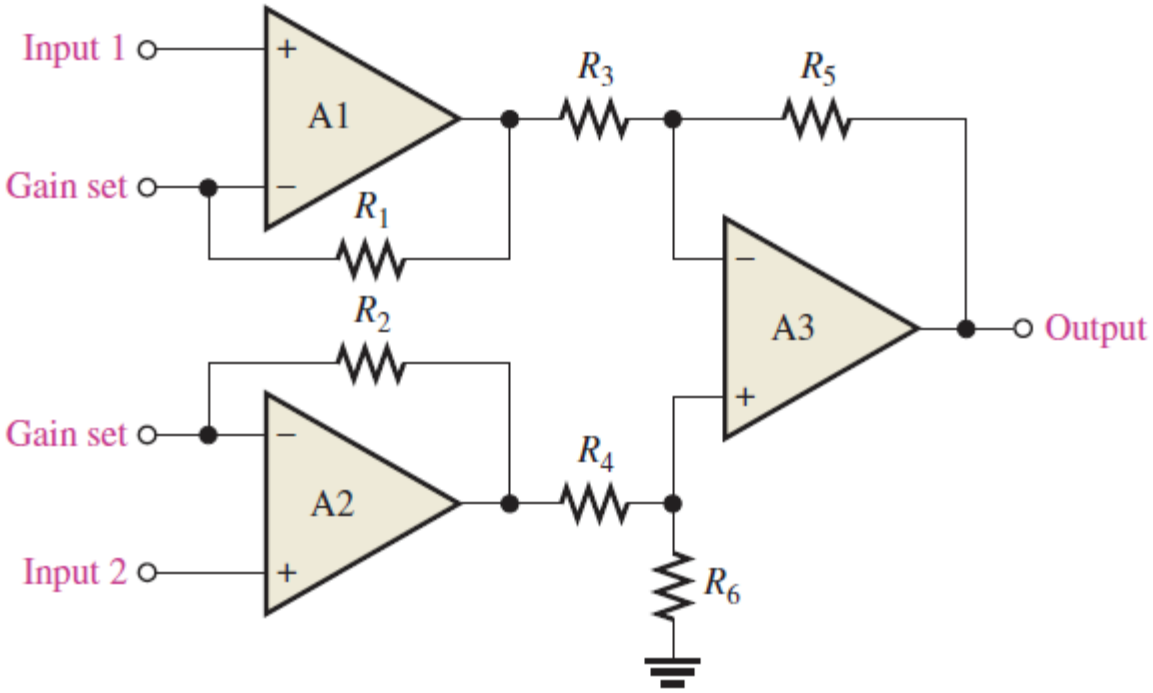
Diferencijalni pojačavač



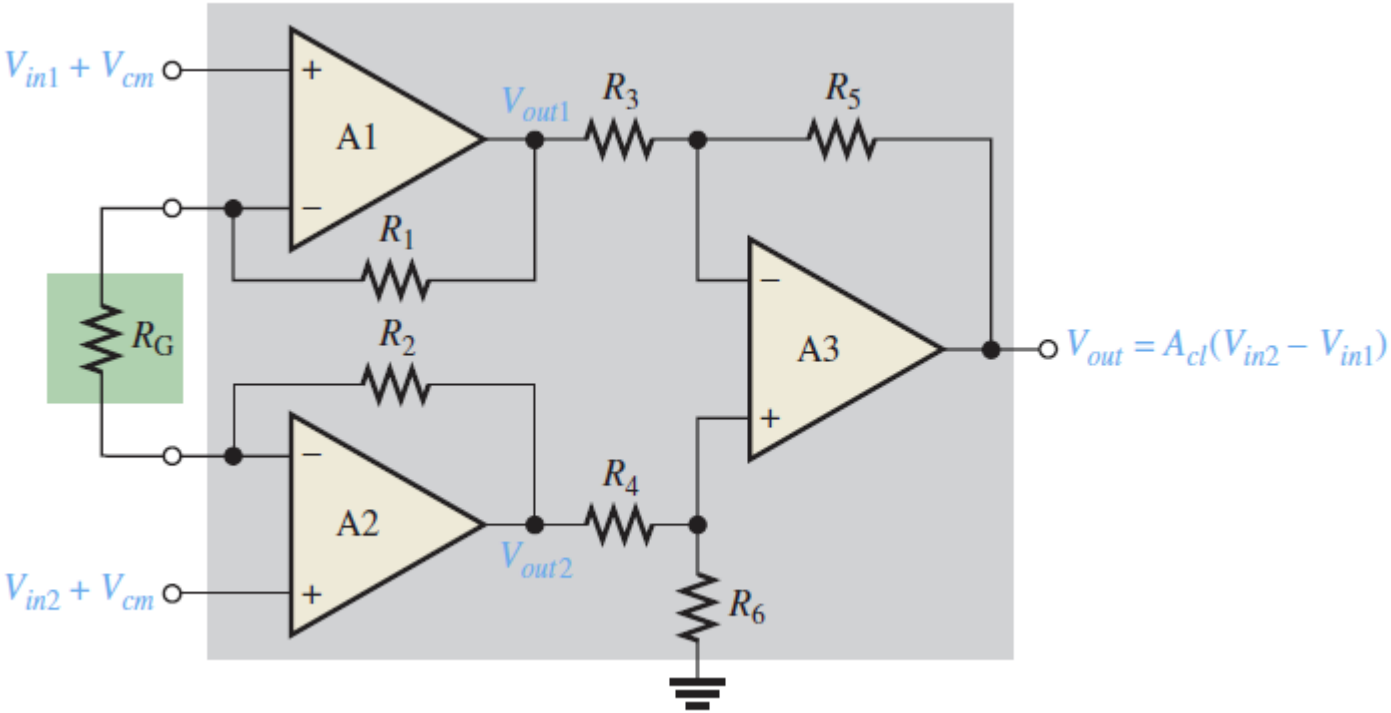
$$V_x = V_1\left(\frac{R_2}{R_1 + R_2}\right) \qquad I_1 = \left(\frac{V_2 - V_y}{R_1}\right) = I_2 \qquad V_o = V_y - I_2 R_2$$

$$a \gg 1 \qquad V_i = 0 \qquad V_y = V_x \qquad V_o = \frac{R_2}{R_1}(V_1 - V_2)$$

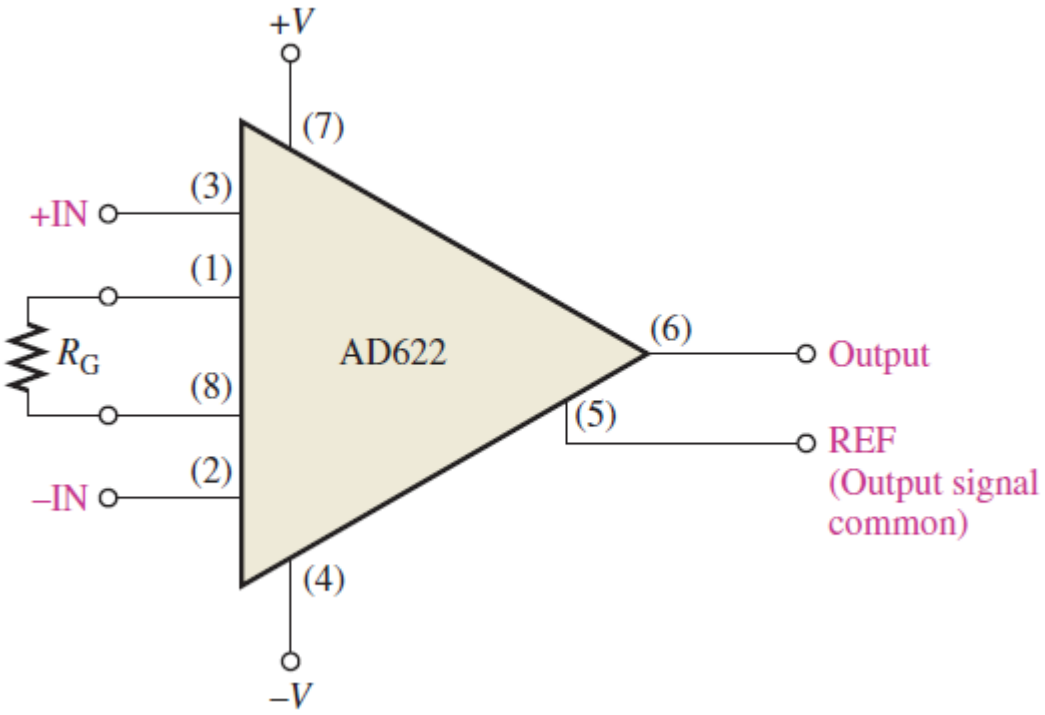
Instrumentacioni pojačavač



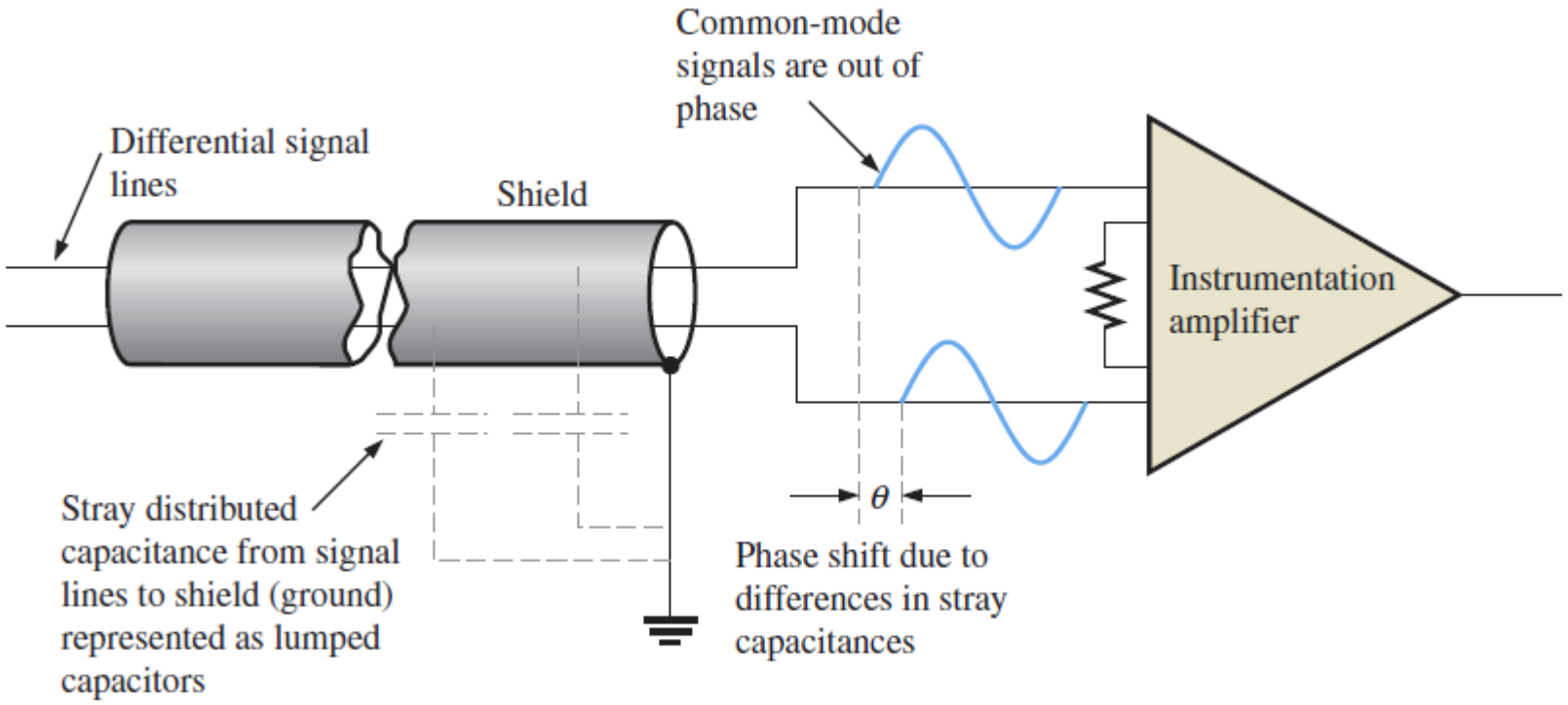
Instrumentacioni pojačavač sa otpornikom za zadavanje pojačanja



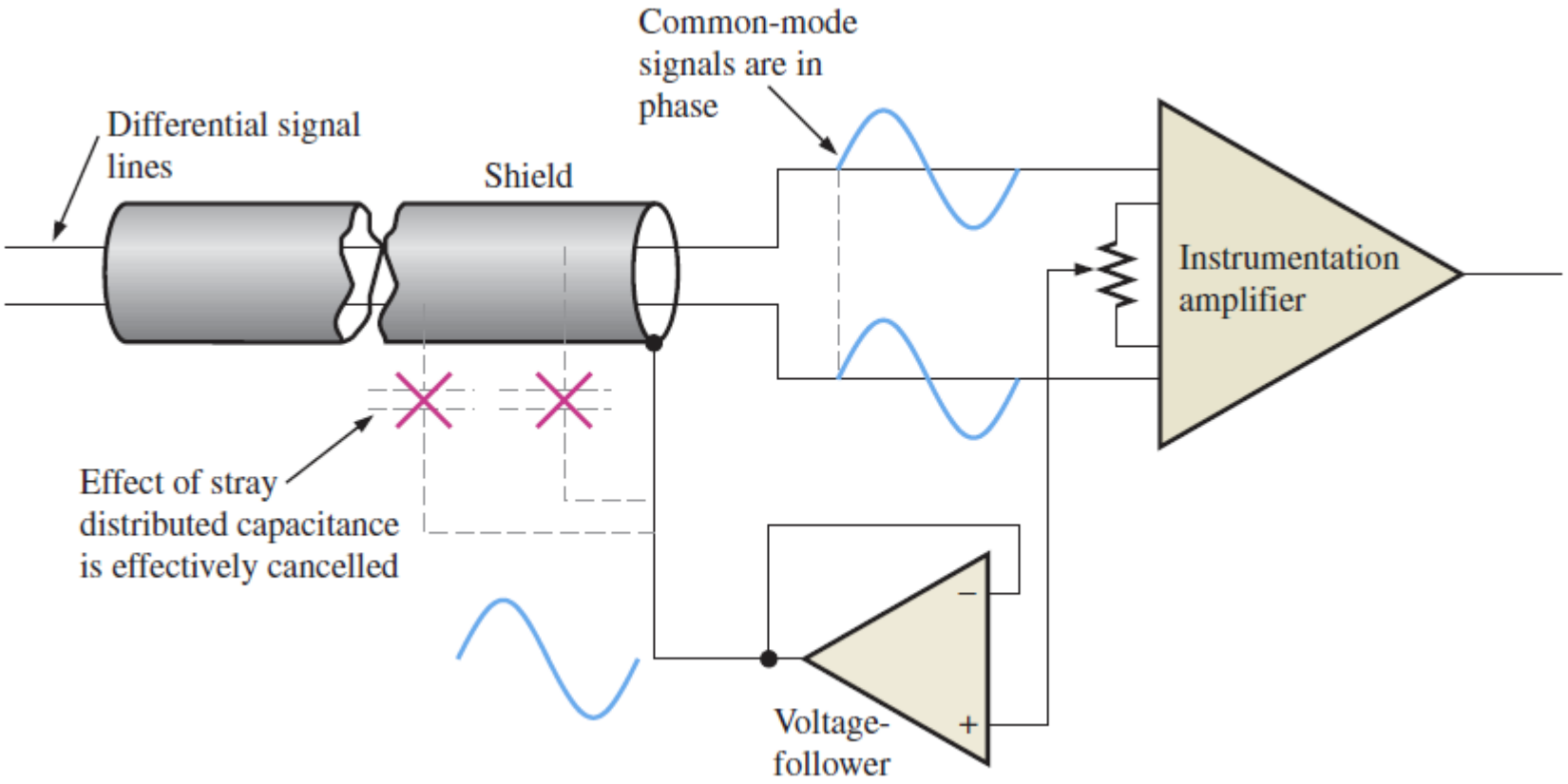
Integrisani instrumentacioni pojačavač sa otpornikom za zadavanje pojačanja



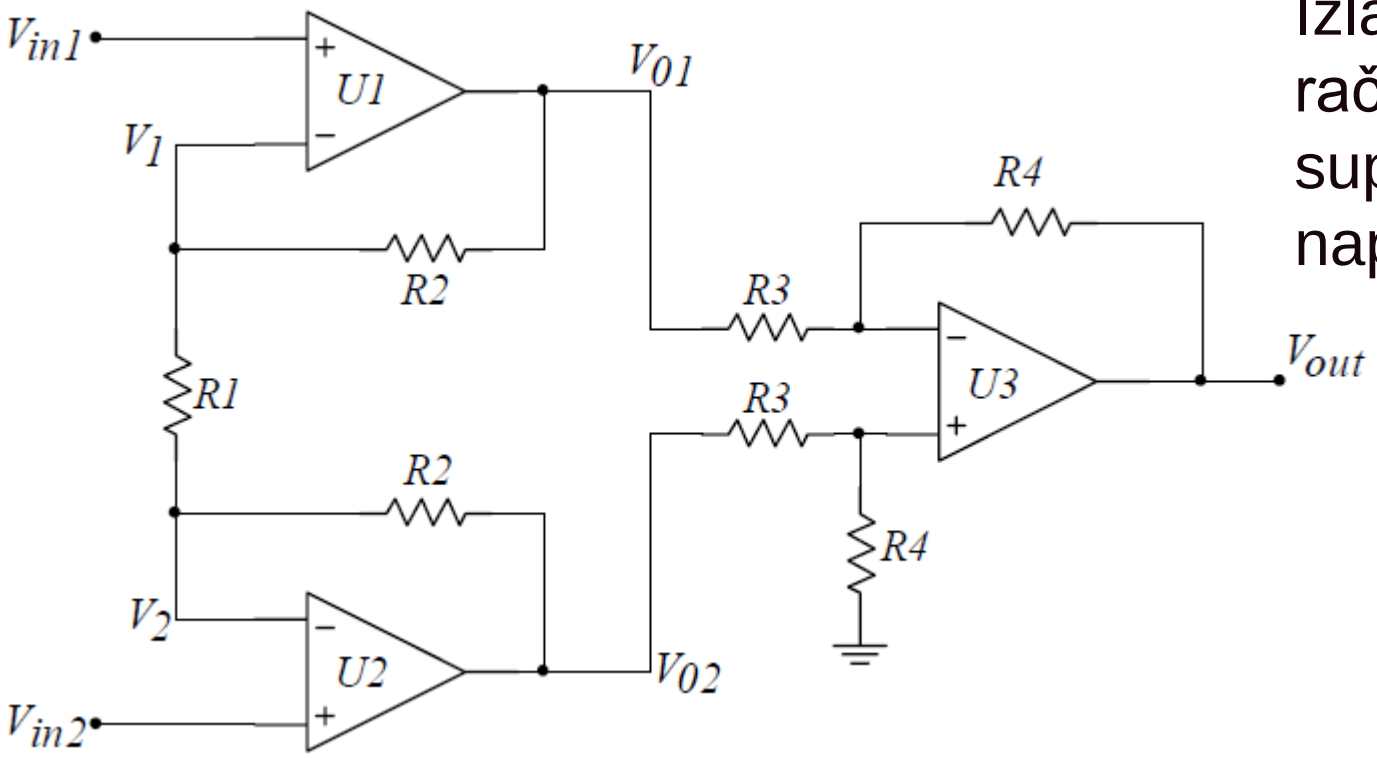
Povezivanje instrumentacionog pojačavača sa udaljenim senzorom



Povezivanje instrumentacionog pojačavača sa udaljenim senzorom



Instrumentacioni pojačavač



Izlazni napon se računa kao superpozicija dva napona:

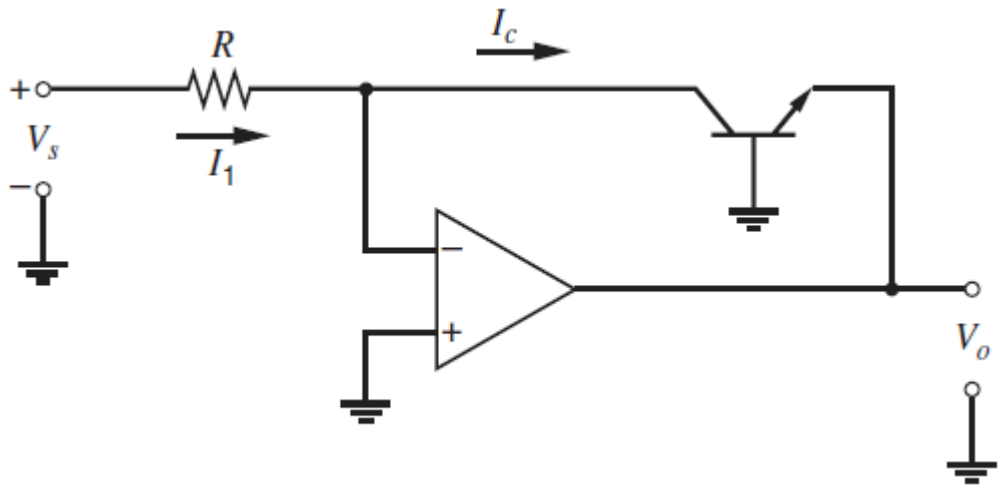
$$V_{01} = \left(1 + \frac{R2}{R1}\right) V_{in1} - \frac{R2}{R1} V_{in2}$$

$$V_{out} = V_{01} + V_{02}$$

$$V_{02} = \left(1 + \frac{R2}{R1}\right) V_{in2} - \frac{R2}{R1} V_{in1}$$

$$V_{out} = \frac{R4}{R3}\left(1 + \frac{2R2}{R1}\right)\left(V_{in2} - V_{in1}\right)$$

Logaritamski pojačavač

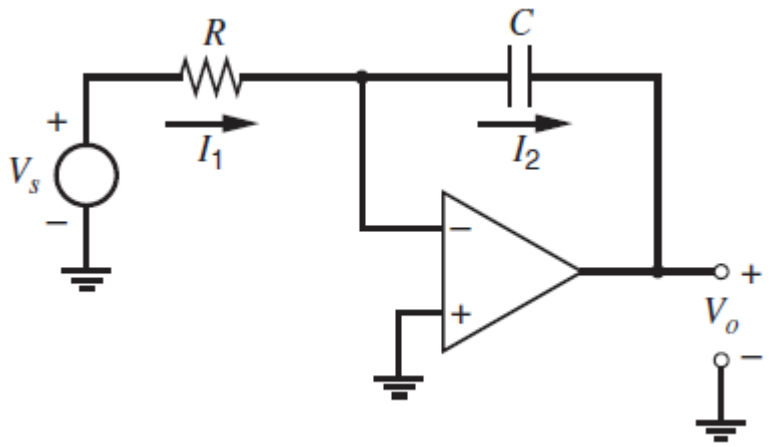


$$I_1 = \frac{V_s}{R} = I_c = I_S \left[\exp\left(\frac{V_{be}}{V_T}\right) - 1\right] \simeq I_S \exp\left(\frac{V_{be}}{V_T}\right)$$

$$V_o = -V_{be}$$

$$V_o = -V_T \ln\left(\frac{V_s}{I_S R}\right)$$

Integrator

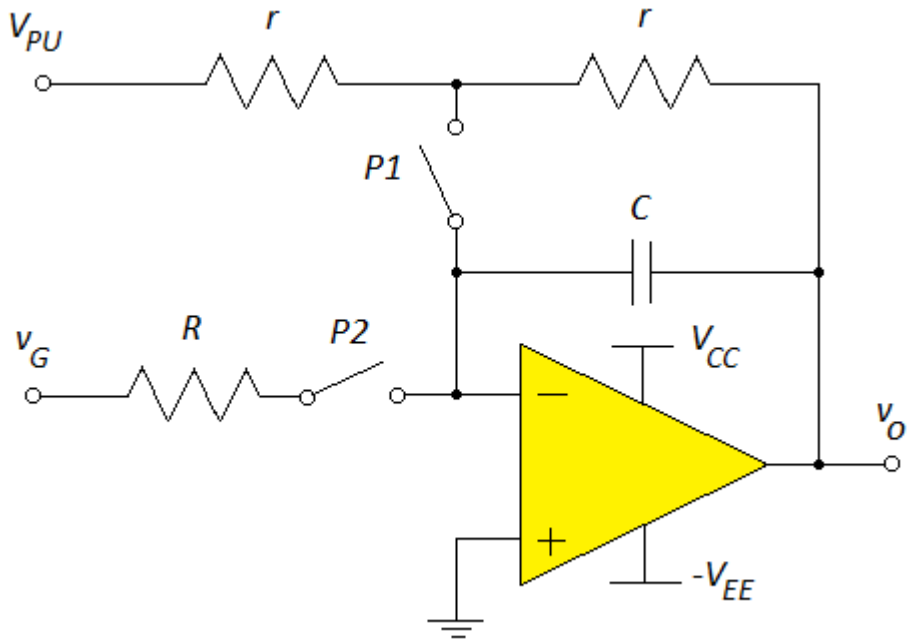


$$I_1 = \frac{V_s}{R} = I_2$$

$$V_o = -\frac{1}{C}\int_0^t I_2 d\tau + V_o(0)$$

$$V_o(t) = -\frac{1}{RC}\int_0^t V_s(\tau) d\tau + V_o(0)$$

Trorežimski integrator

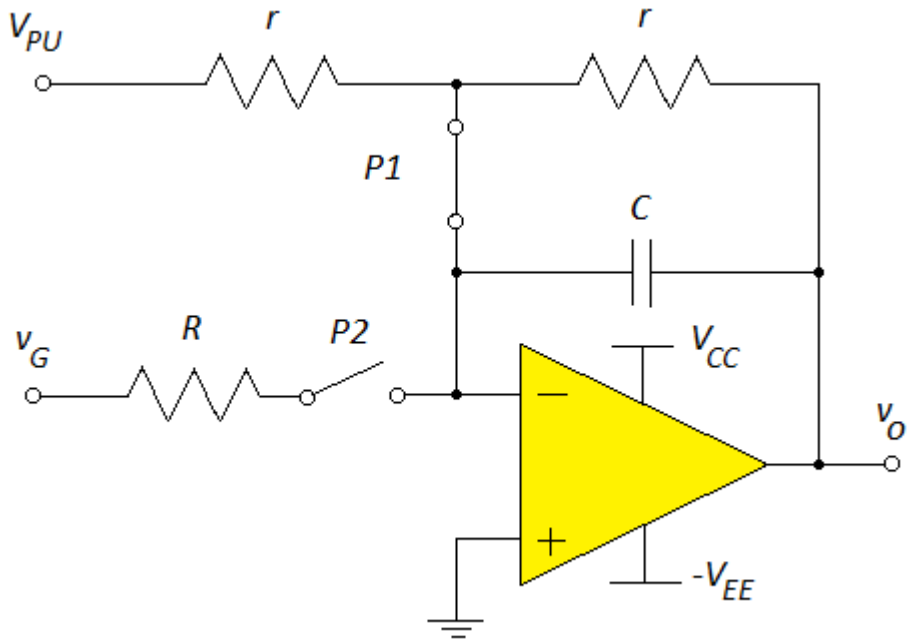


Tri režima rada u zavisnosti od položaja prekidača *P1* i *P2* su:

- postavljanje početnih uslova
- integracija
- pamćenje.

Otpornici *r* se kompromisno biraju da budu što manji za brže postavljanje početnih uslova, ali i što veći za ograničenje izlazne struje operacionog pojačavača u režimima integracije i pamćenja.

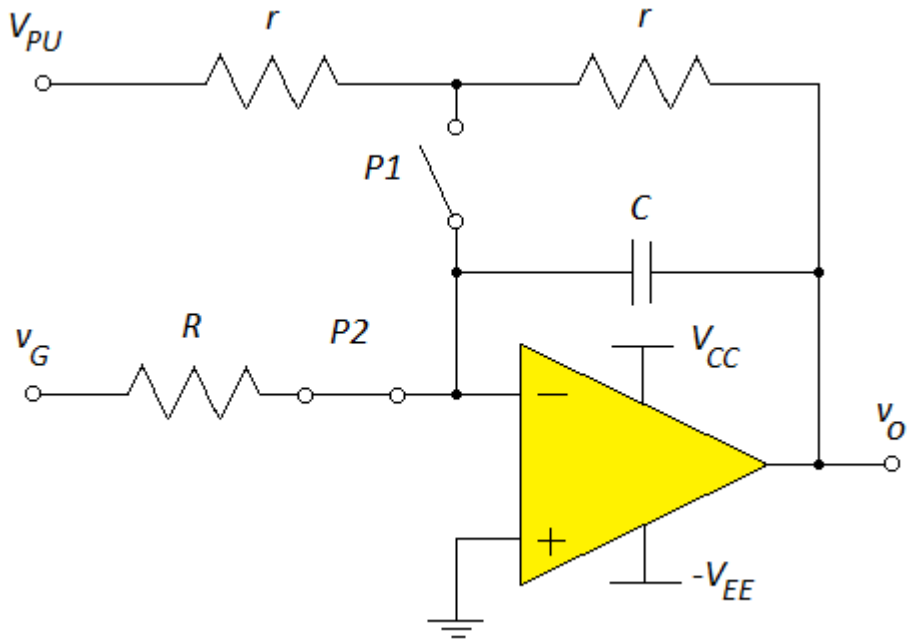
Trorežimski integrator
režim postavljanja početnih uslova



Na kraju postavljanja početnih uslova, struja kroz kondenzator *C* je nula, tako da pojačavač radi kao invertujući pojačavač.

$$v_O = -\frac{r}{r} V_{PU} = -V_{PU}$$

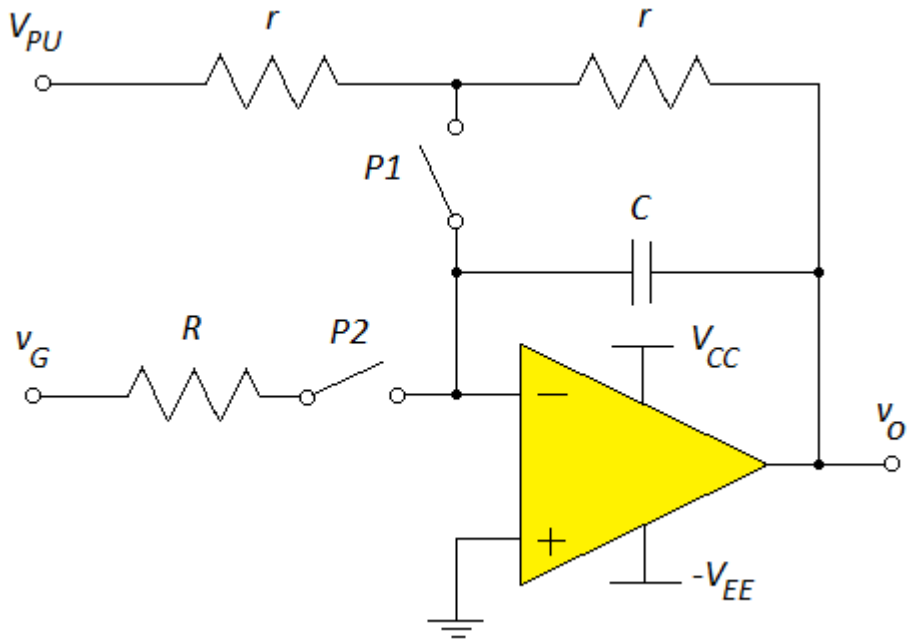
Trorežimski integrator
režim integracije



Na kraju režima integracije, izlazni napon je:

$$v_O(T_{INT}) = -V_{PU} - \frac{1}{RC}\int_0^{T_{INT}} v_G(t)dt$$

Trorežimski integrator režim pamćenja

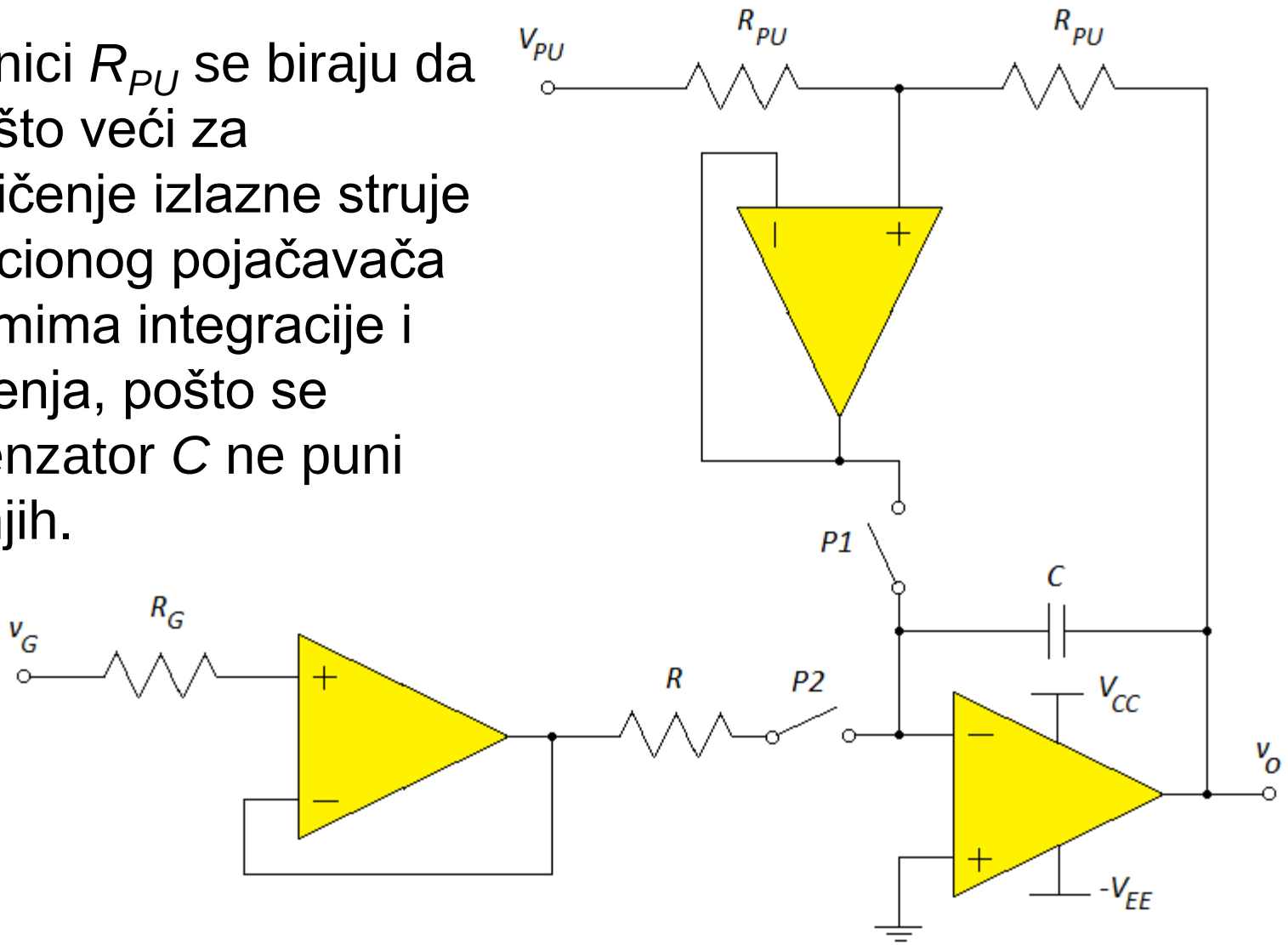


Na kraju režima pamćenja, izlazni napon je:

$$v_O(T_{PAM}) = -V_{PU} - \frac{1}{RC}\int_0^{T_{INT}} v_G(t)dt$$

Trorežimski integrator sa brzim postavljanjem početnih uslova

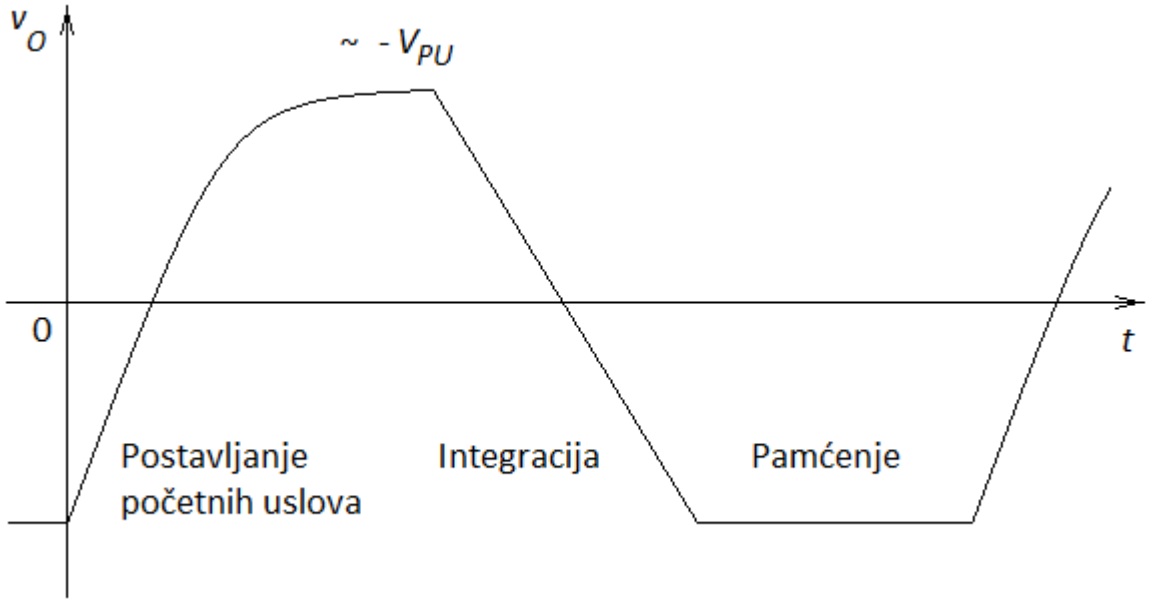
Otpornici R_{PU} se biraju da budu što veći za ograničenje izlazne struje operacionog pojačavača u režimima integracije i pamćenja, pošto se kondenzator C ne puni kroz njih.



Trorežimski integrator vremenski dijagrami

Primer: $V_{PU} < 0$ i $v_G = \text{const} > 0$

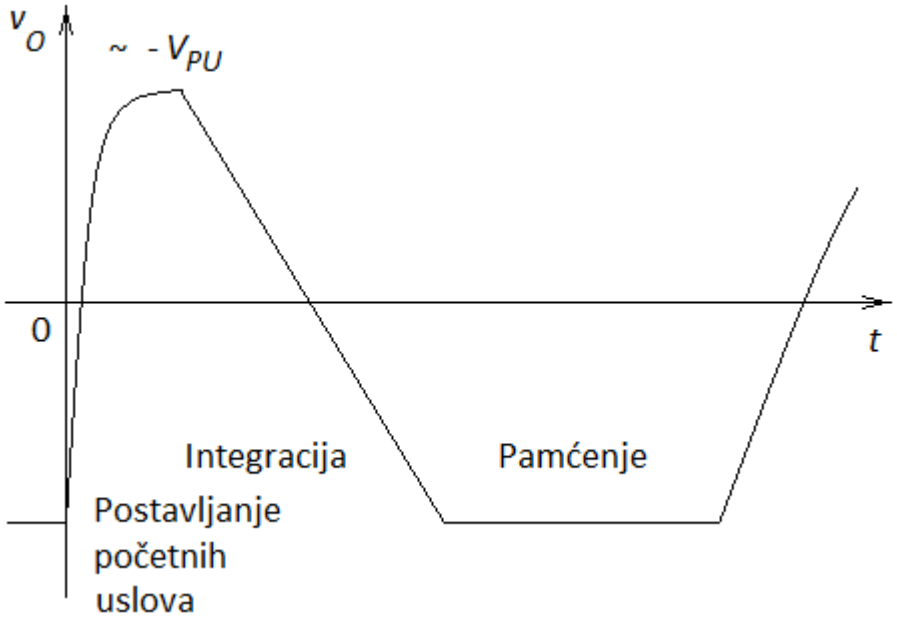
Za vreme režima integracije, izlazni napon je: $v_O(t) = -V_{PU} - \frac{V_G}{RC}t$



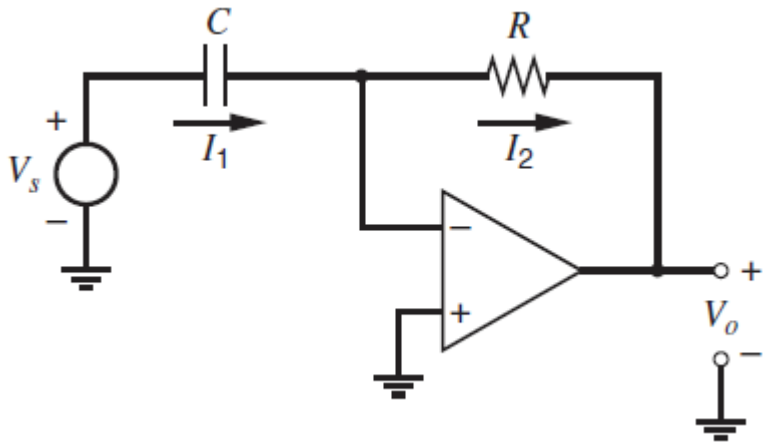
Trorežimski integrator sa brzim zadavanjem početnih uslova vremenski dijagrami

Primer: $V_{PU} < 0$ i $v_G = \text{const} > 0$

Za vreme režima integracije, izlazni napon je: $v_O(t) = -V_{PU} - \frac{V_G}{RC}t$



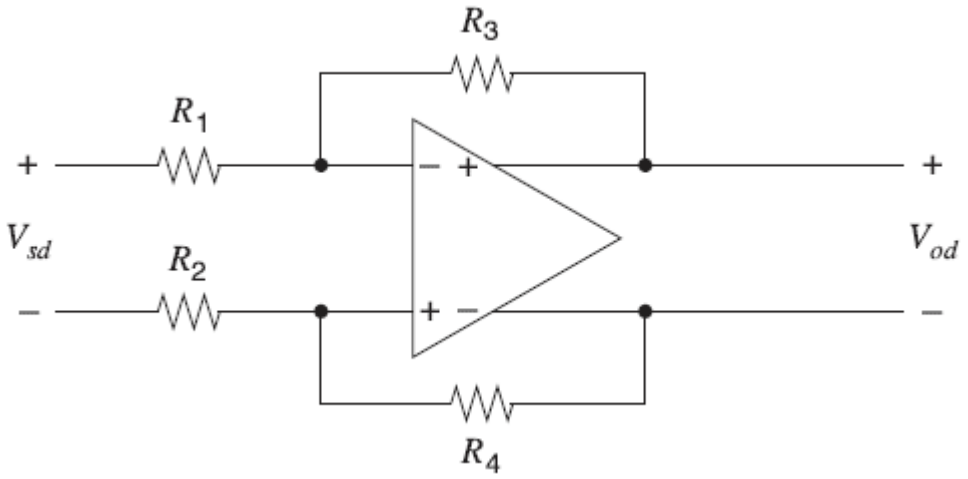
Diferencijator



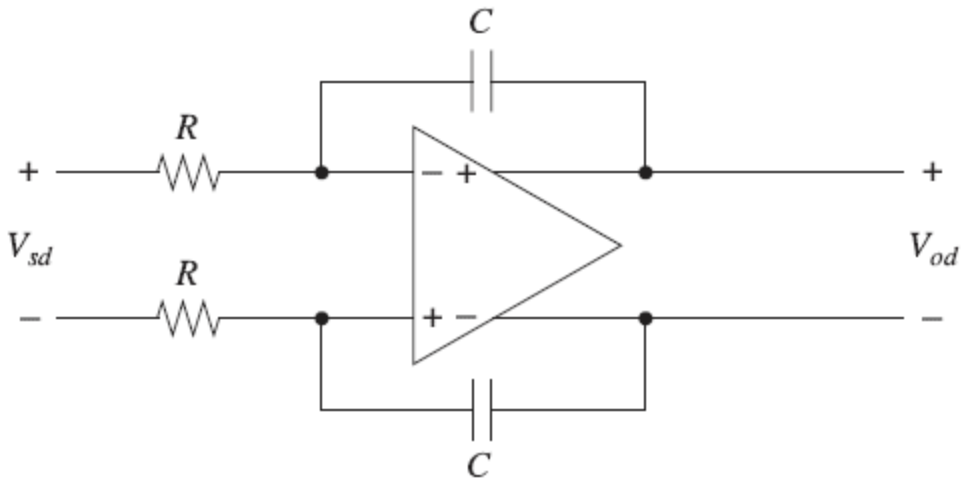
$$I_1 = C\frac{dV_s}{dt} = I_2$$

$$V_o = -RI_2 = -RC\frac{dV_s}{dt}$$

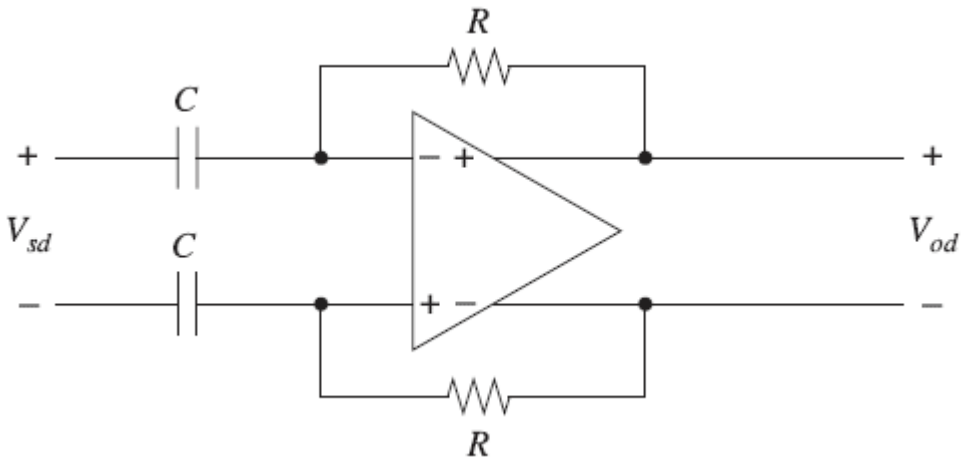
Diferencijalni invertujući pojačavač



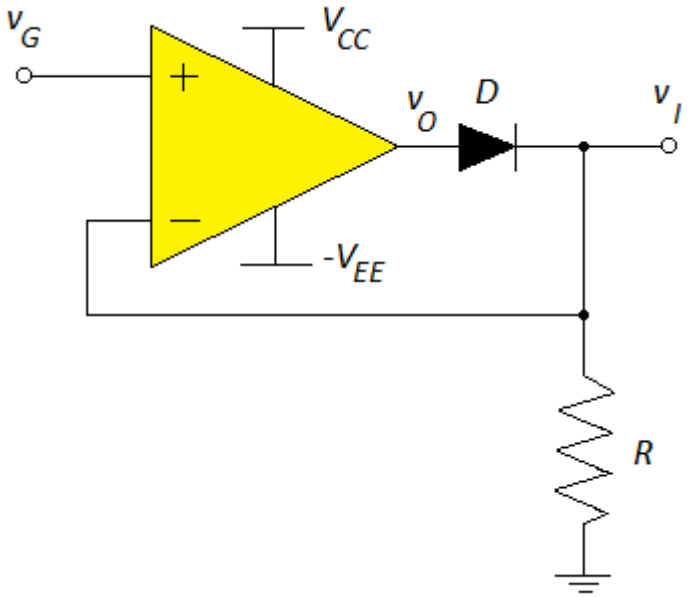
Diferencijalni integrator



Diferencijalni diferencijator



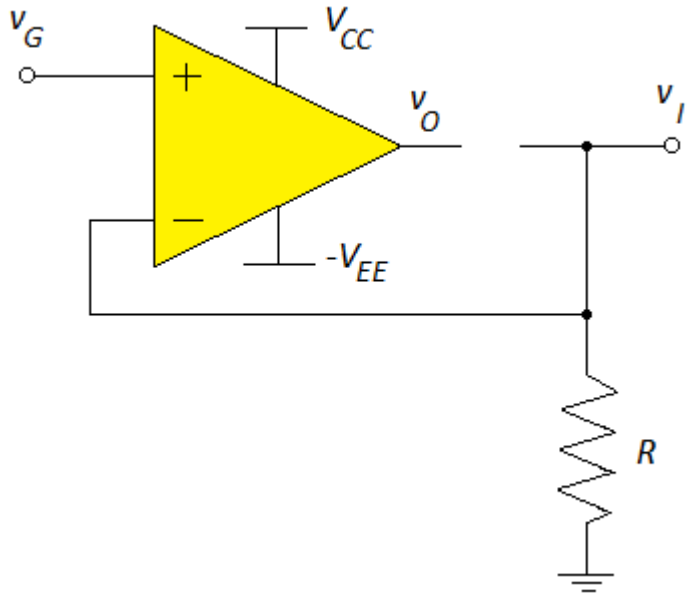
Polutalasni usmerač sa jednom diodom i operacionim pojačavačem

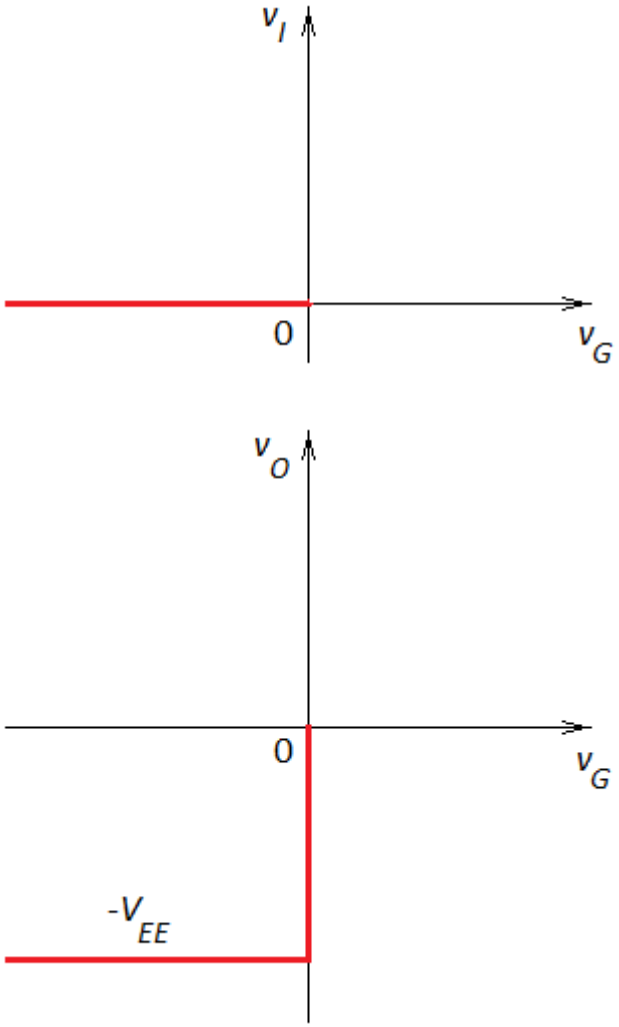


Ukupno postoji 8 varijanti kola u zavisnosti od:

- Smera diode *D* (prikazanog ili obrnutog)
- Izvora za napajanje ($V_R < 0$) umesto mase na otporniku *R*
- Izvora za napajanje ($V_R > 0$) umesto mase na otporniku *R*

Polutalasni usmerač sa jednom diodom i beskonačnim pojačanjem

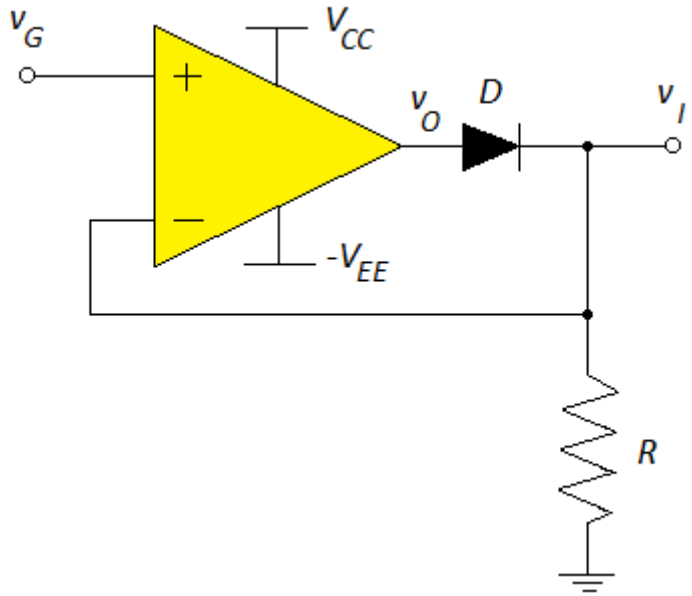


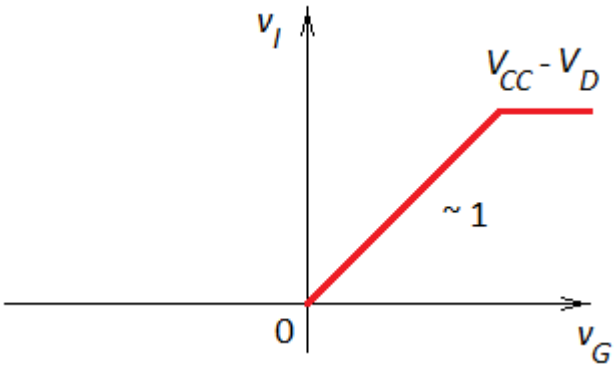


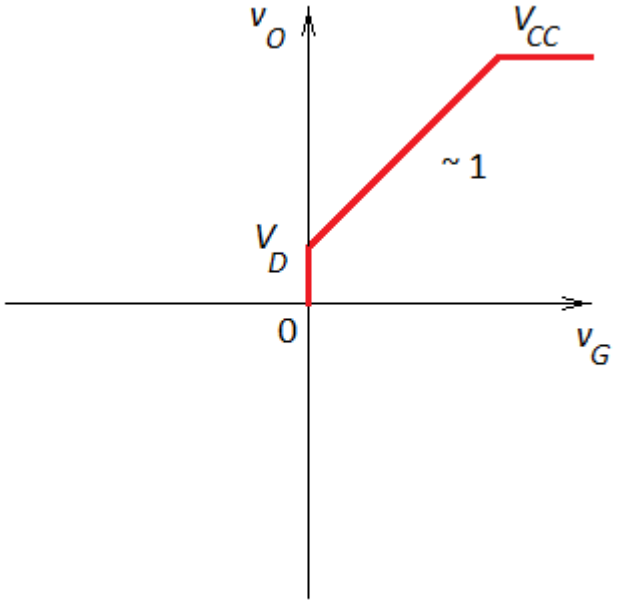
Dioda ne vodi, pa ne postoji negativna povratna sprega.

$v_G < 0 \qquad v_I = 0 \qquad v_O = -V_{EE}$

Polutalasni usmerač sa jednom diodom i beskonačnim pojačanjem



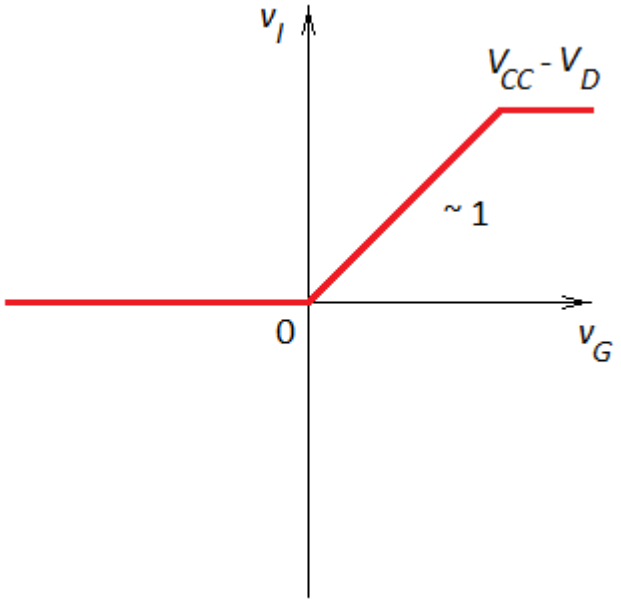


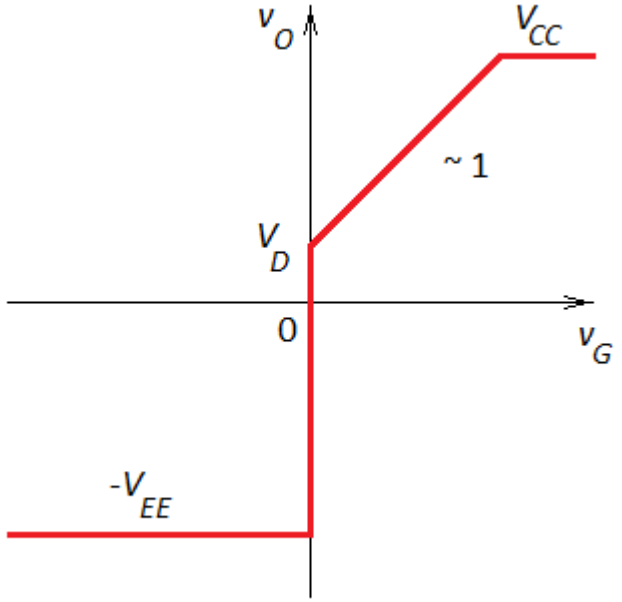


Dioda vodi, pa postoji negativna povratna sprega.

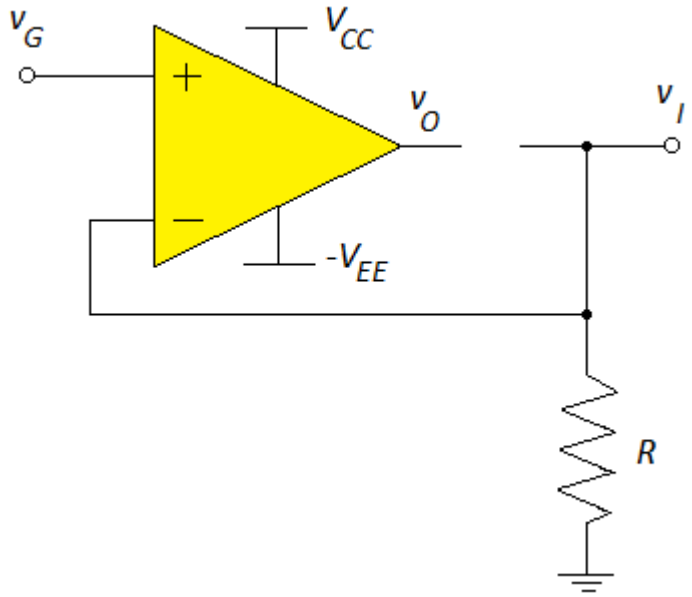
$v_G \geq 0 \qquad v_I = v_G \qquad v_O = v_G + V_D$

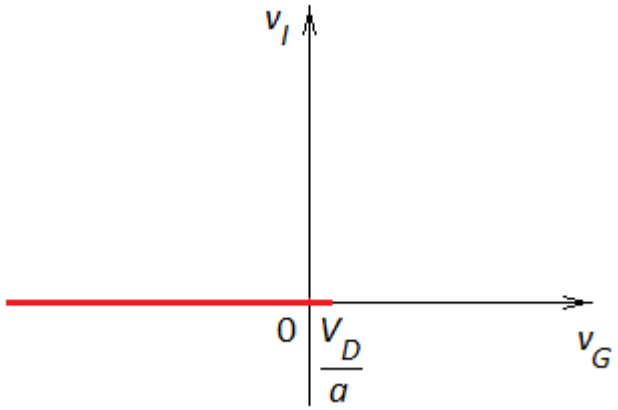
Polutalasni usmerač sa jednom diodom i beskonačnim pojačanjem

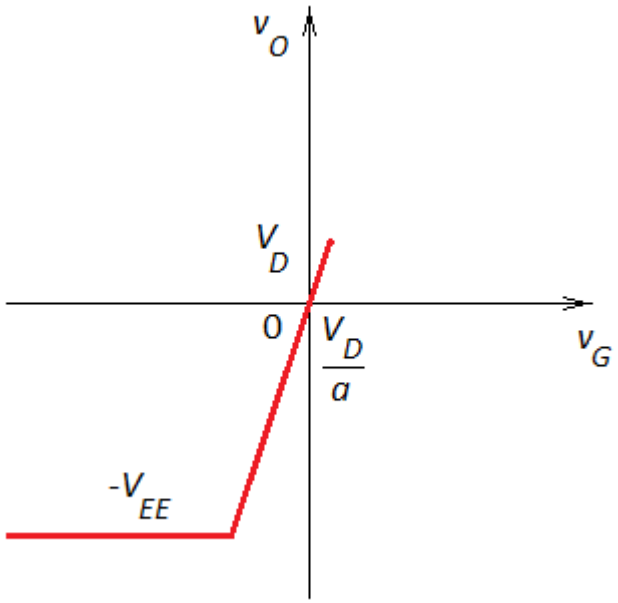




Polutalasni usmerač sa jednom diodom i konačnim pojačanjem



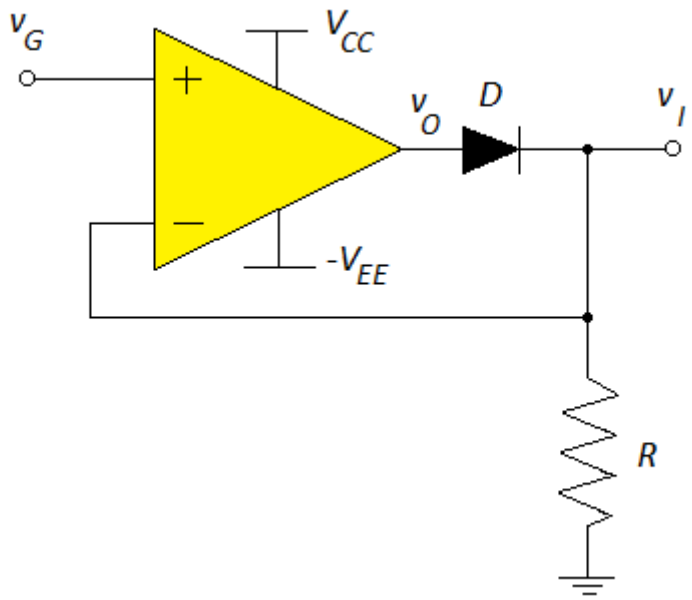




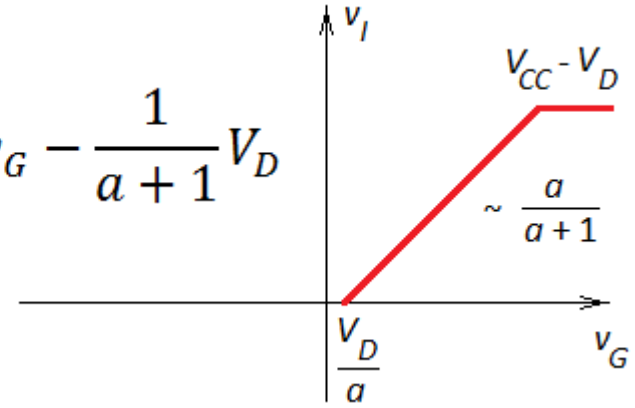
Dioda ne vodi, pa ne postoji negativna povratna sprega.

$$v_G < \frac{V_D}{a} \qquad v_I = 0 \qquad v_O = a v_G \qquad v_O = -V_{EE}$$

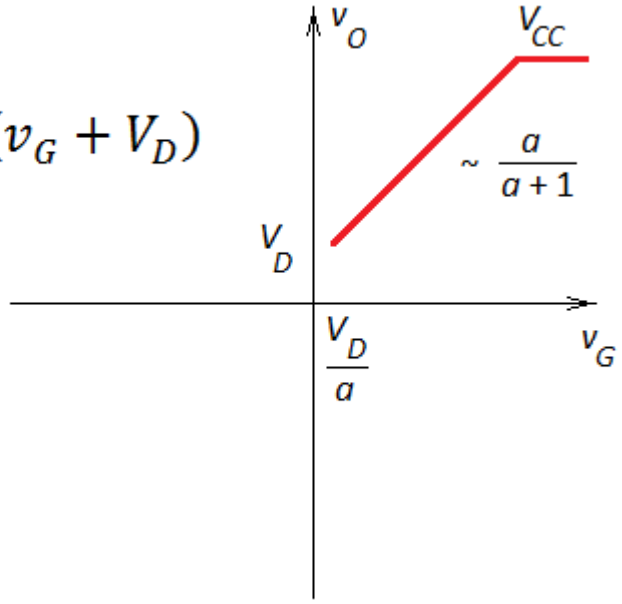
Polutalasni usmerač sa jednom diodom i konačnim pojačanjem



$$v_I = \frac{a}{a+1} v_G - \frac{1}{a+1} V_D$$



$$v_O = \frac{a}{a+1}(v_G + V_D)$$

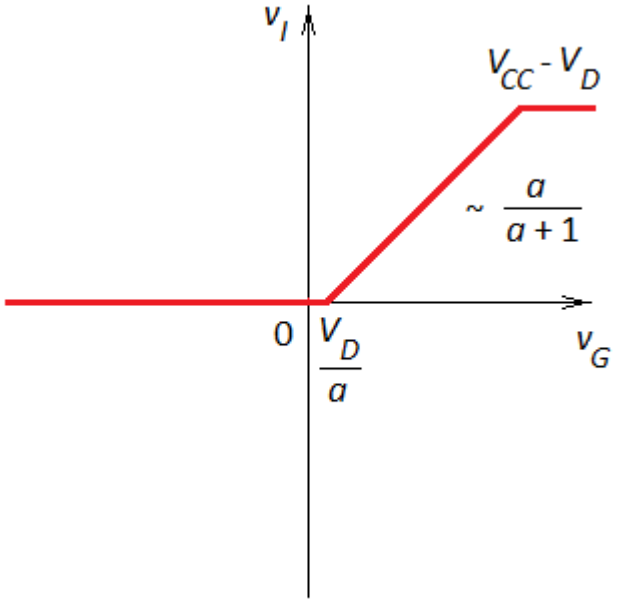


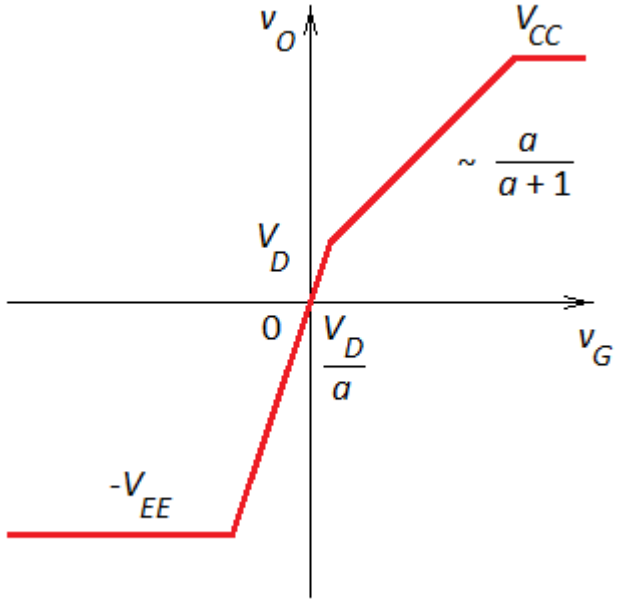
$$v_G \geq \frac{V_D}{a} \qquad v_O = a(v_G - v_I)$$

$$v_O = v_I + V_D \qquad a(v_G - v_I) = v_I + V_D$$

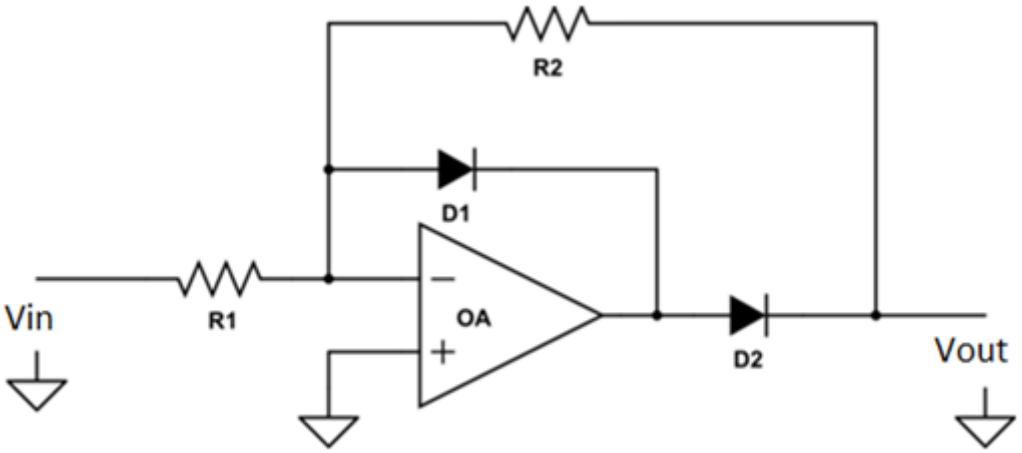
$$a v_G = (a+1) v_I + V_D$$

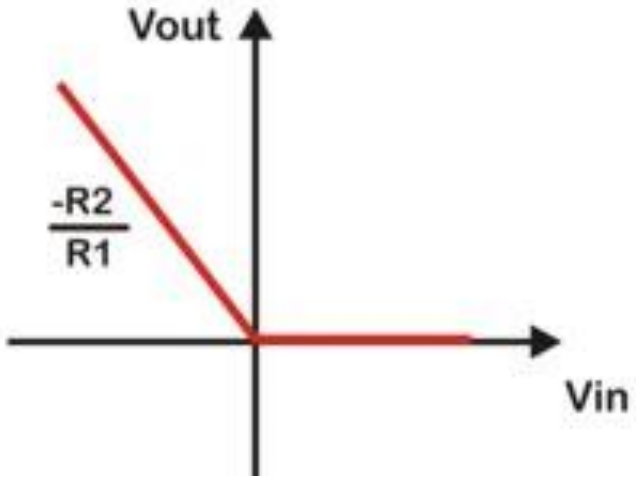
Polutalasni usmerač sa jednom diodom i konačnim pojačanjem



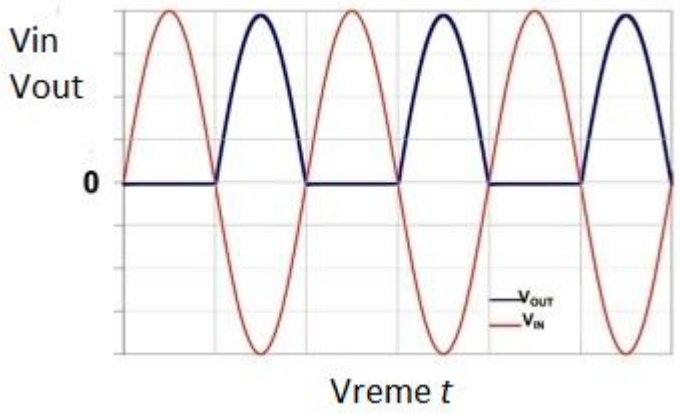


Polutalasni usmerač sa dve diode (šema, prenosna funkcija i vremenski dijagrami)

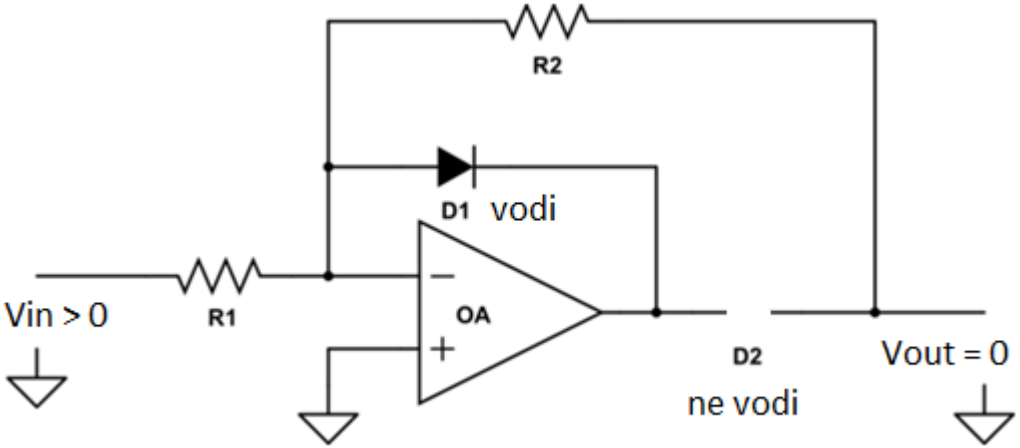


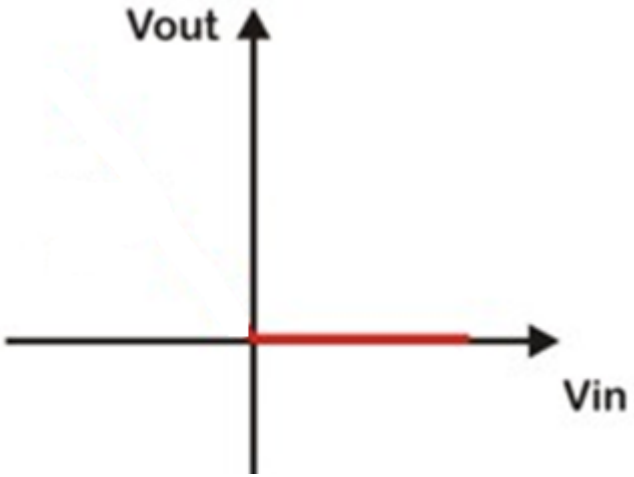


Negativna povratna sprega ne menja polaritet signala na ulazu pojačavača, tako da je ulaz na invertujućem (-) priključku pozitivan za pozitivan Vin, i negativan za negativno Vin.



Polutalasni usmerač sa dve diode (šema, prenosna funkcija i vremenski dijagrami)



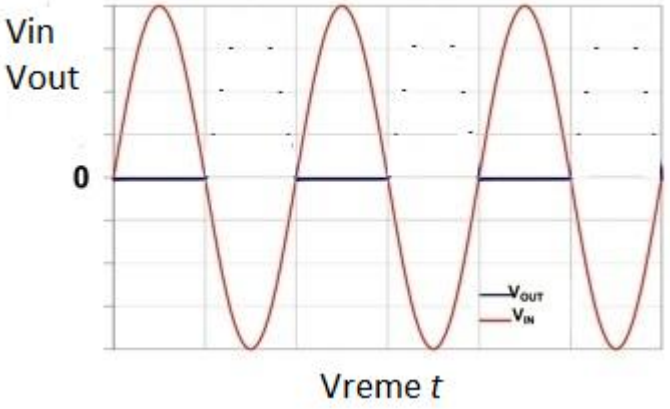


$$v^+ = 0$$

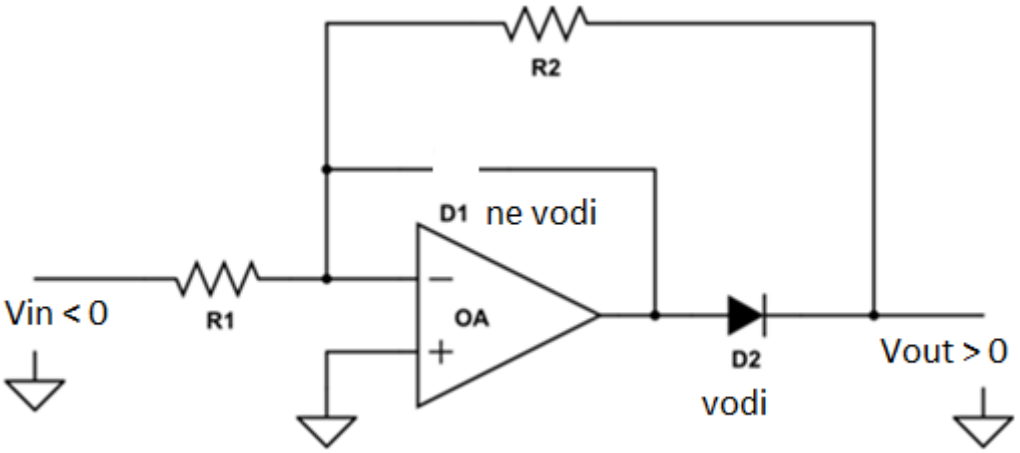
$$v^- = 0^+ = 0 + \varepsilon, \varepsilon > 0, \varepsilon \to 0$$

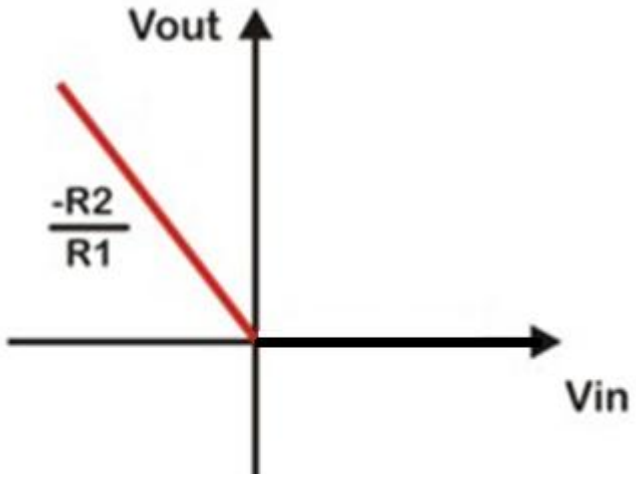
$$v_{OA} = a(v^+ - v^-) = -av^- = -a\varepsilon < 0, a \to \infty$$

$$v_{OA} = -V_{D1} < 0$$



Polutalasni usmerač sa dve diode (šema, prenosna funkcija i vremenski dijagrami)



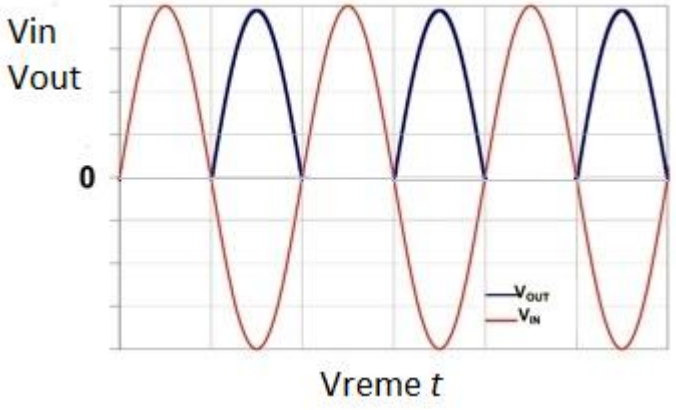


$$v^+ = 0$$

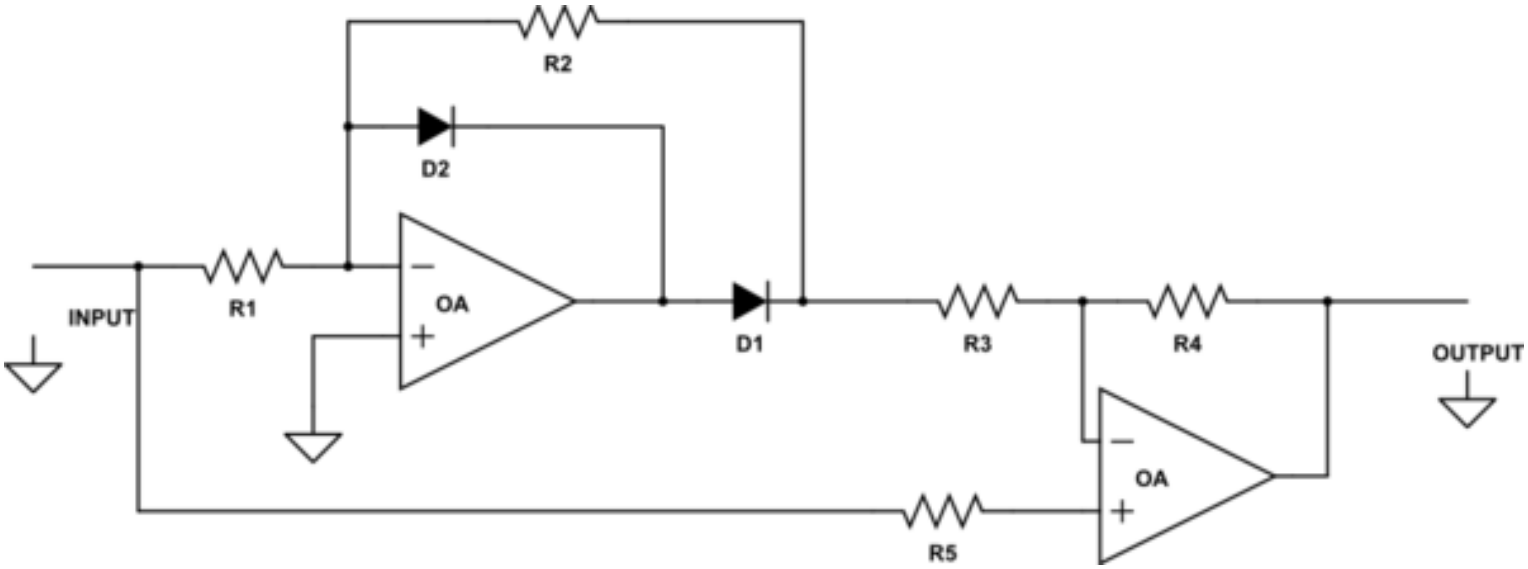
$$v^- = 0^- = 0 - \varepsilon, \varepsilon > 0, \varepsilon \to 0$$

$$v_{OA} = a(v^+ - v^-) = -av^- = a\varepsilon > 0, a \to \infty$$

$$v_{OA} = V_{D2} - \frac{R_2}{R_1} V_{in} > 0$$



Punotalasni usmerač sa dve diode



Osnovi analogne elektronike
IV semestar

KOLA SA OPERACIONIM POJAČAVAČIMA I NEGATIVNOM POVRATNOM SPREGOM