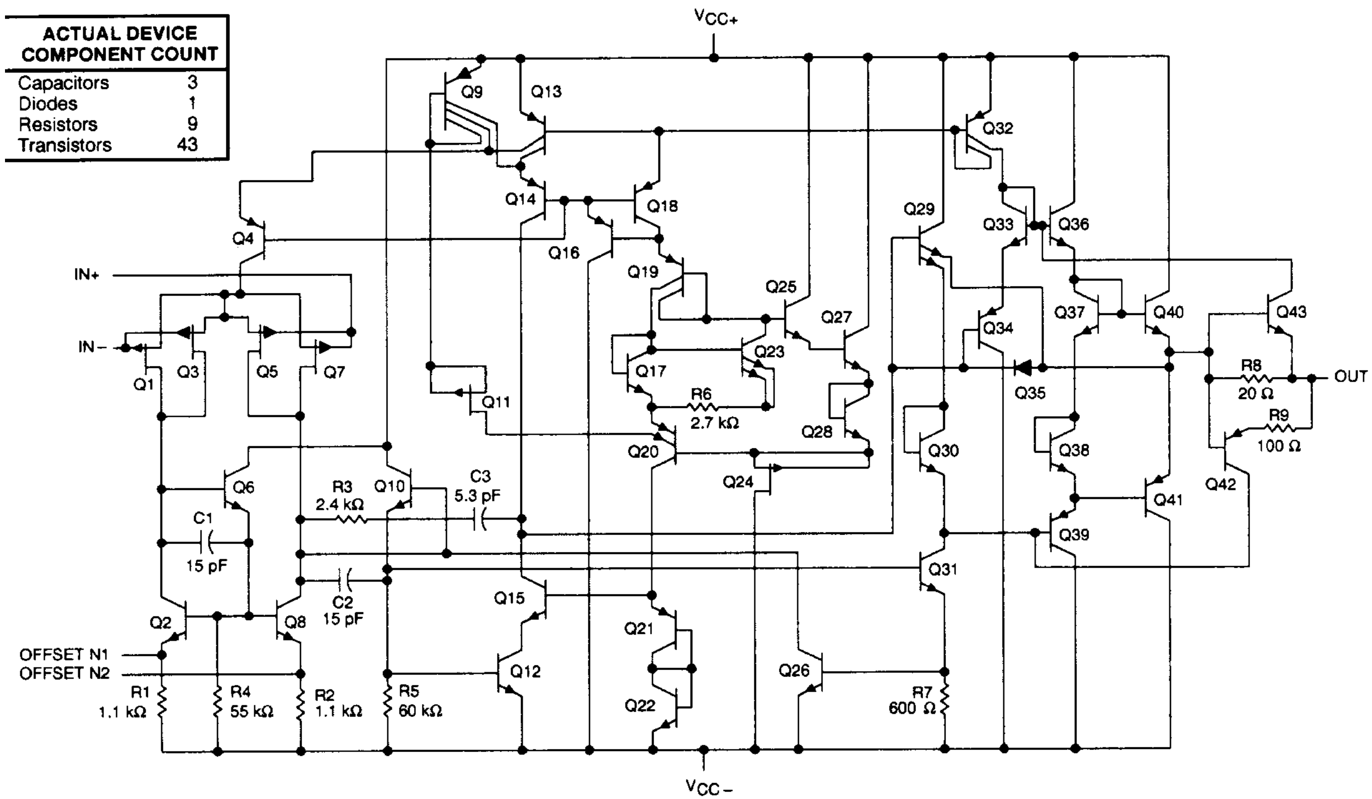
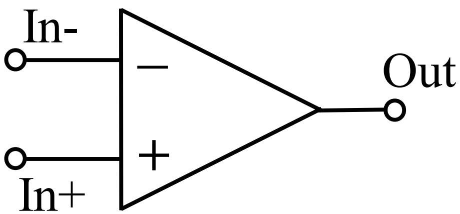
Operacijski ojačevalnik

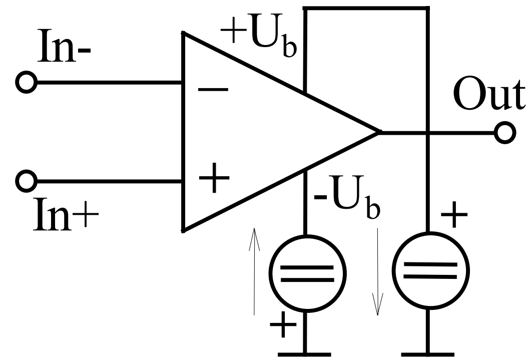
Operacijski ojačevalnik:izvajanje osnovnih matematičnih operacij v dobi analognih računalnikov (+,-,integriranje, diferenciranje,...)



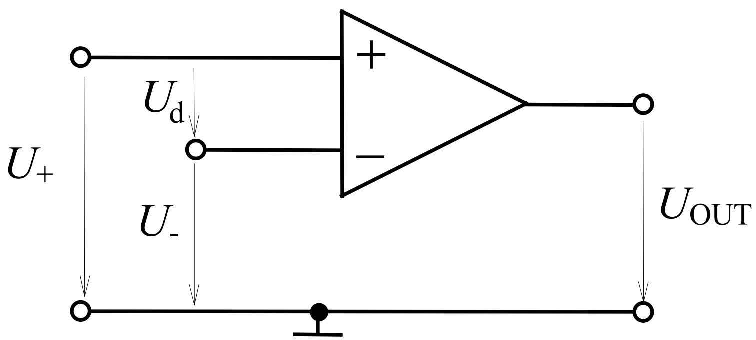
Operacijski ojačevalnik

Obravnava s stališča "črne škatle"





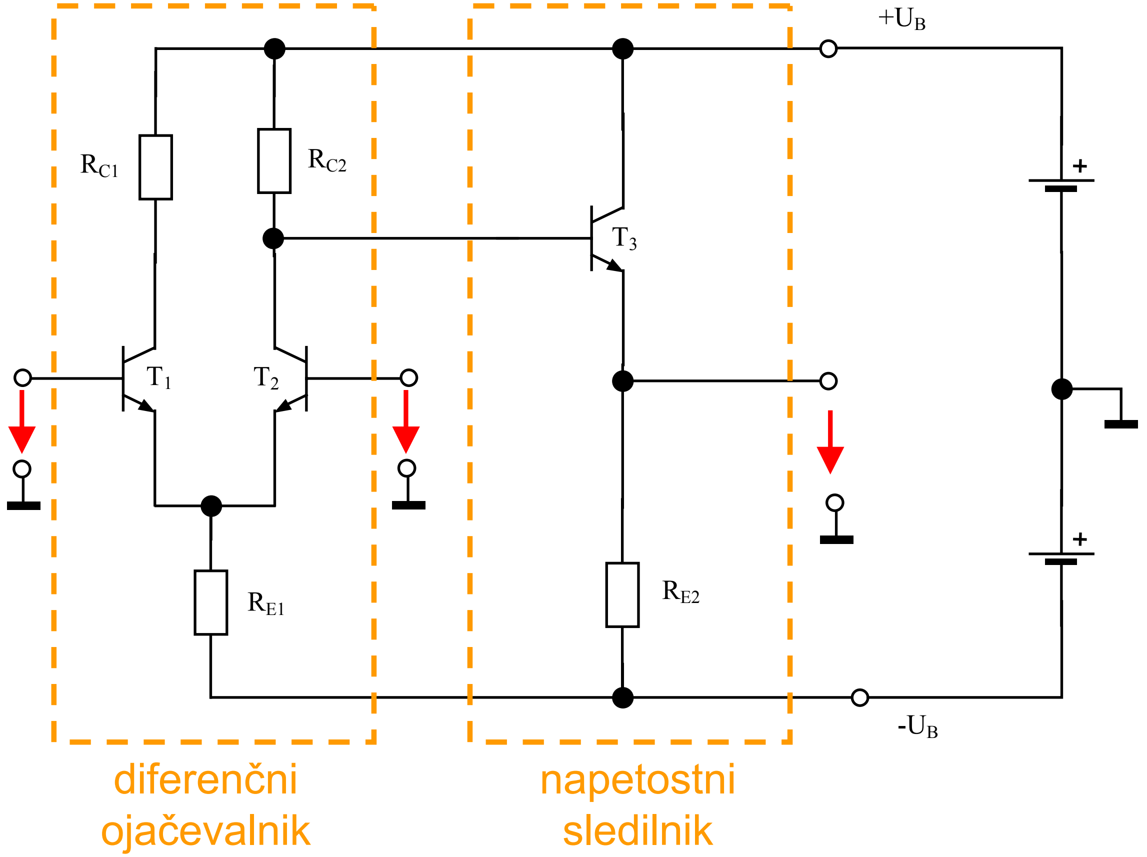
Označevanje napetosti



$$U_{OUT} = U_d \cdot A_d$$

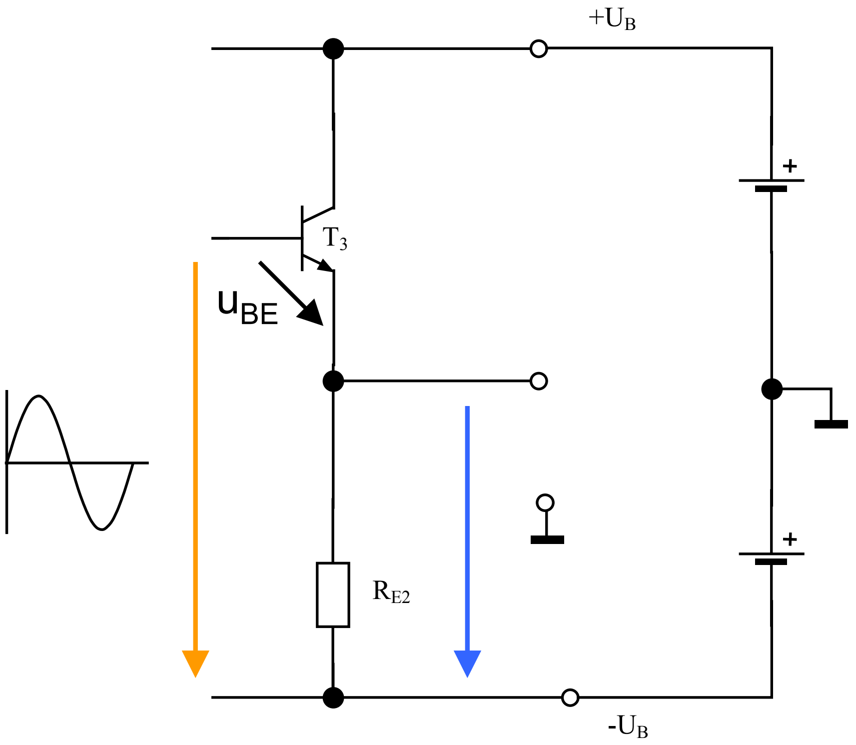
Operacijski ojačevalnik

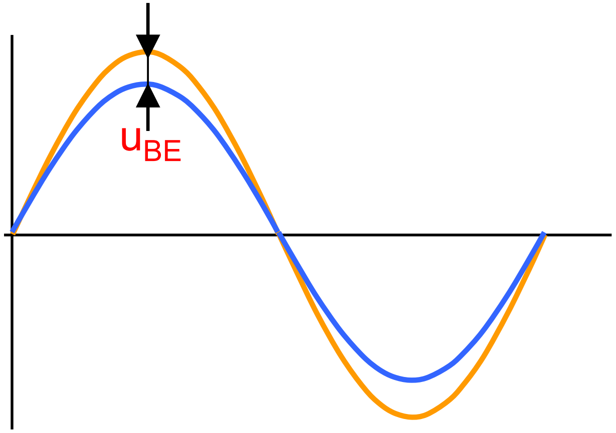
Poenostavljeno vezje operacijskega vezja



Operacijski ojačevalnik

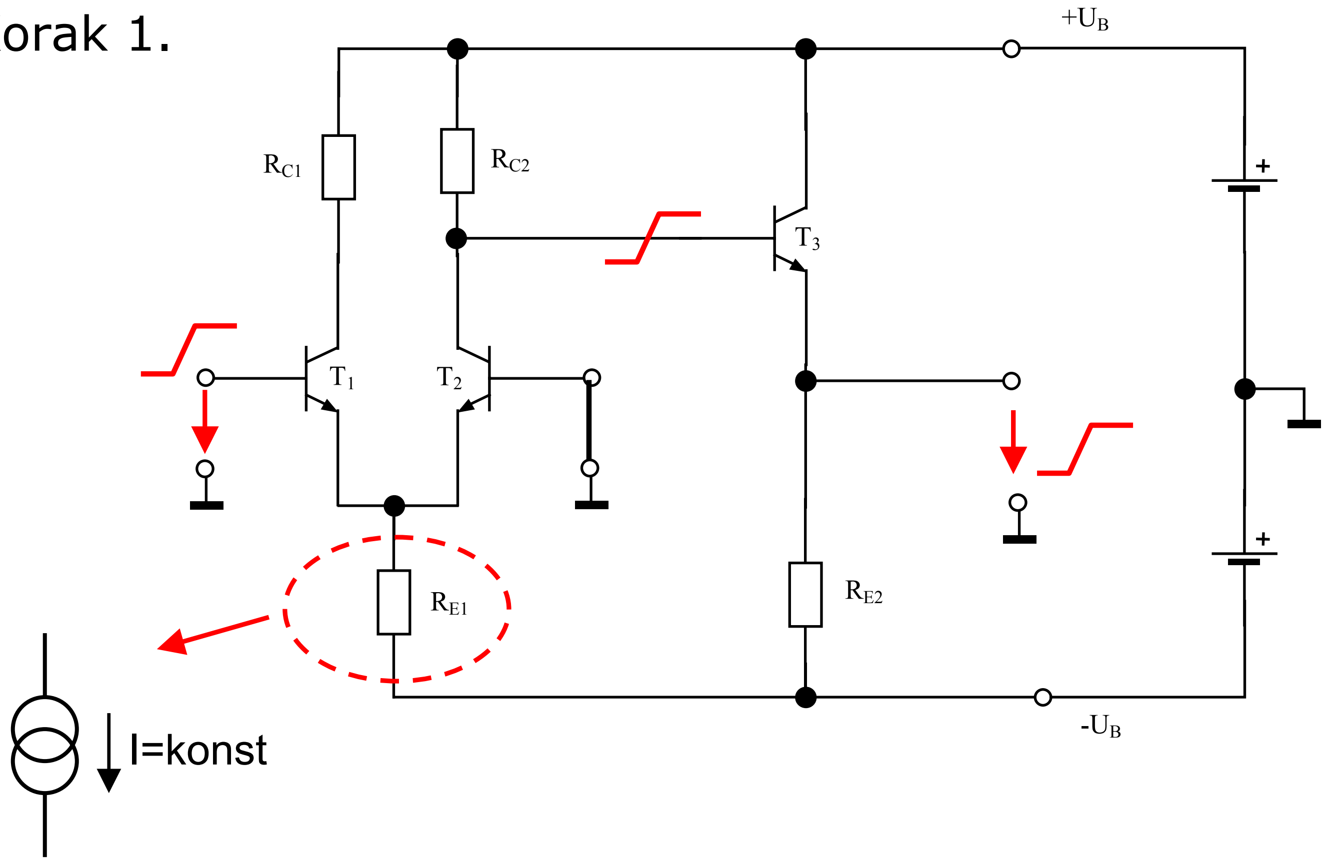
Napetostni sledilnik





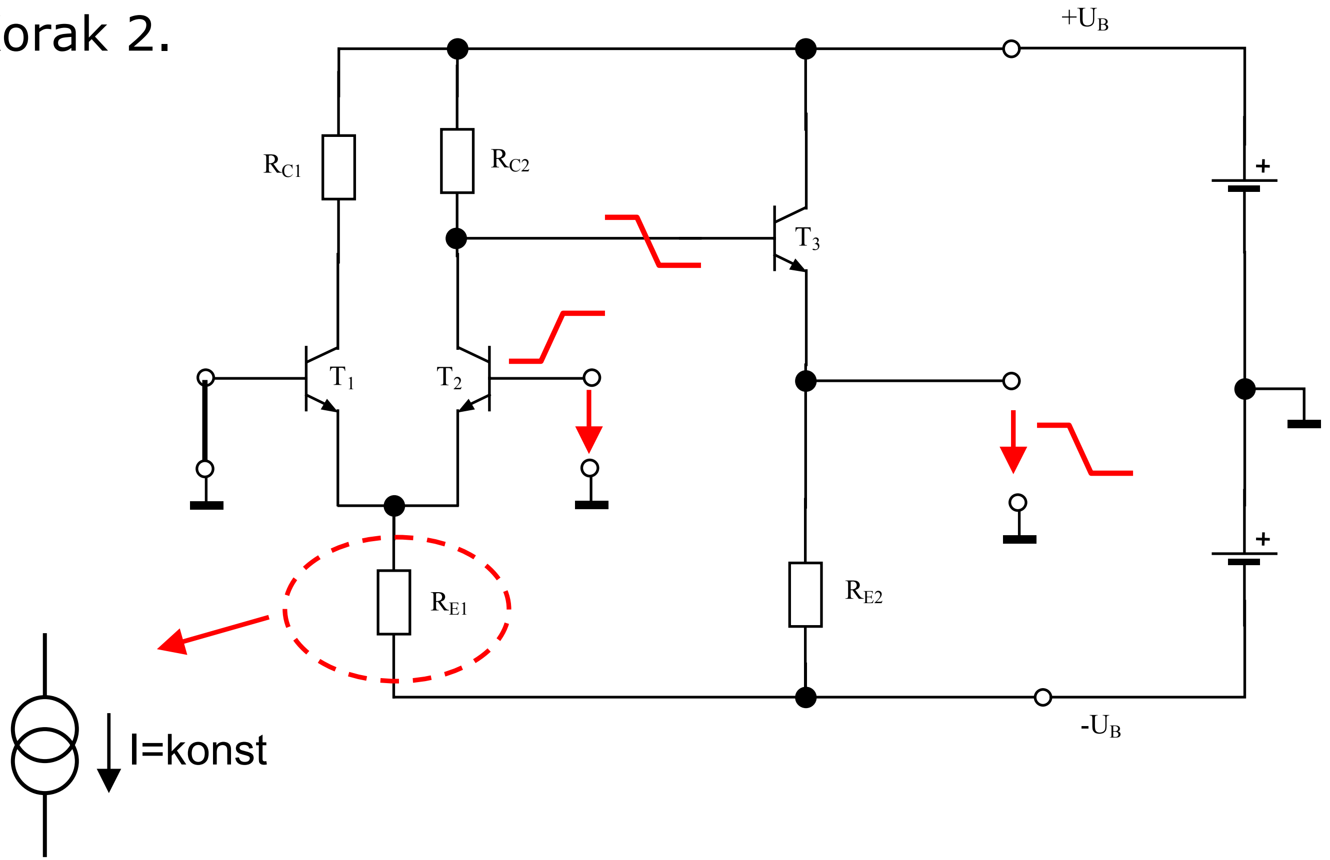
Operacijski ojačevalnik

Korak 1.

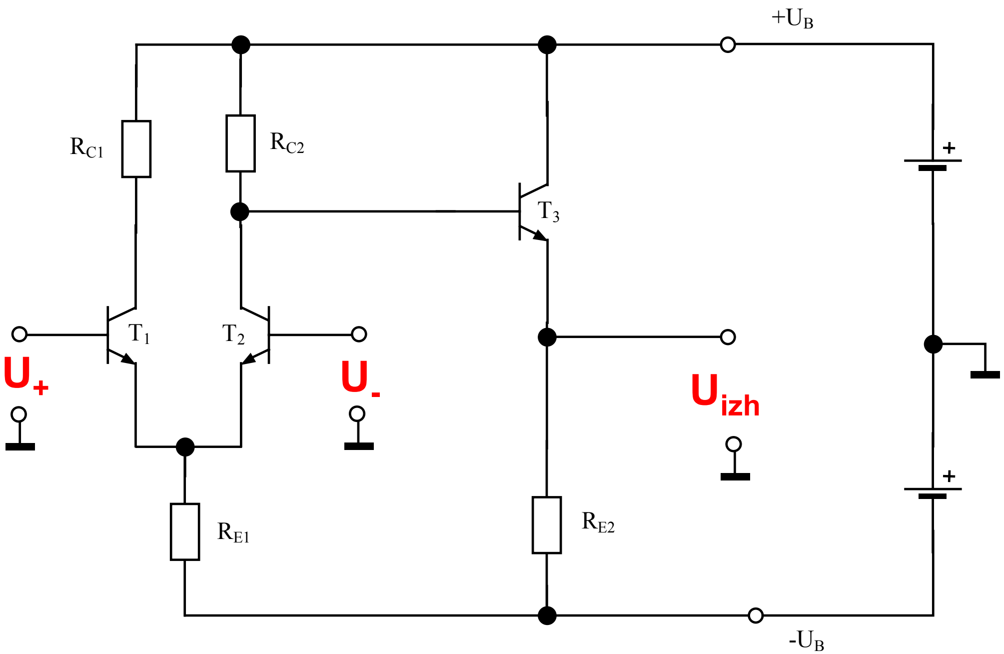


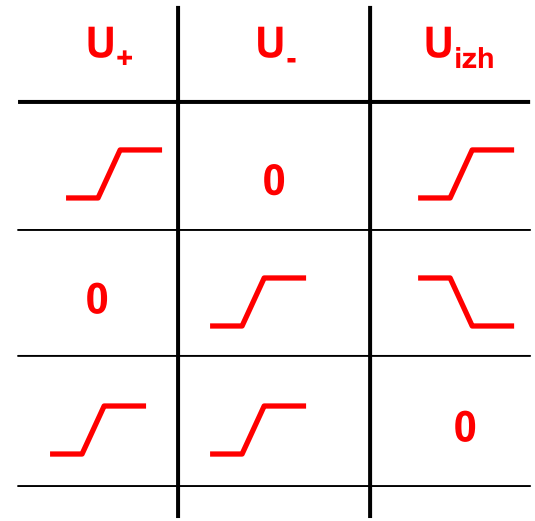
Operacijski ojačevalnik

Korak 2.



Operacijski ojačevalnik



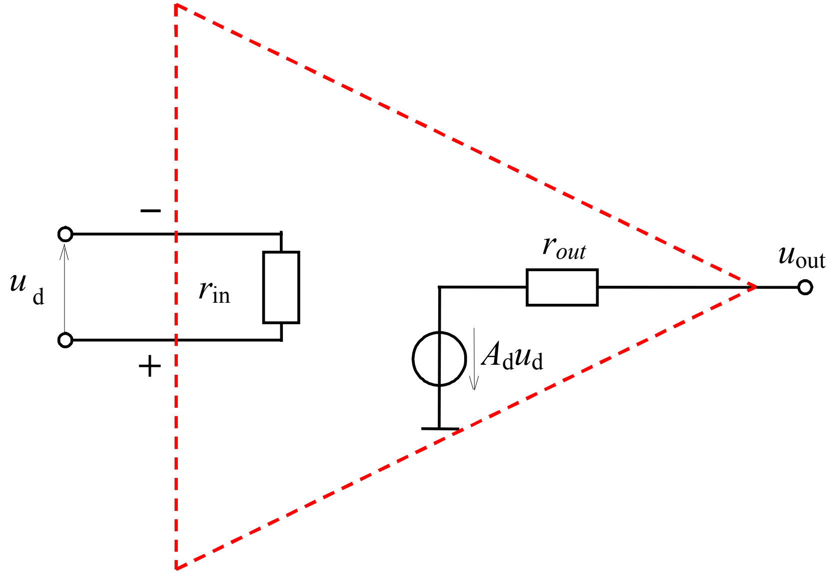


0 … ni spremembe

Operacijski ojačevalnik

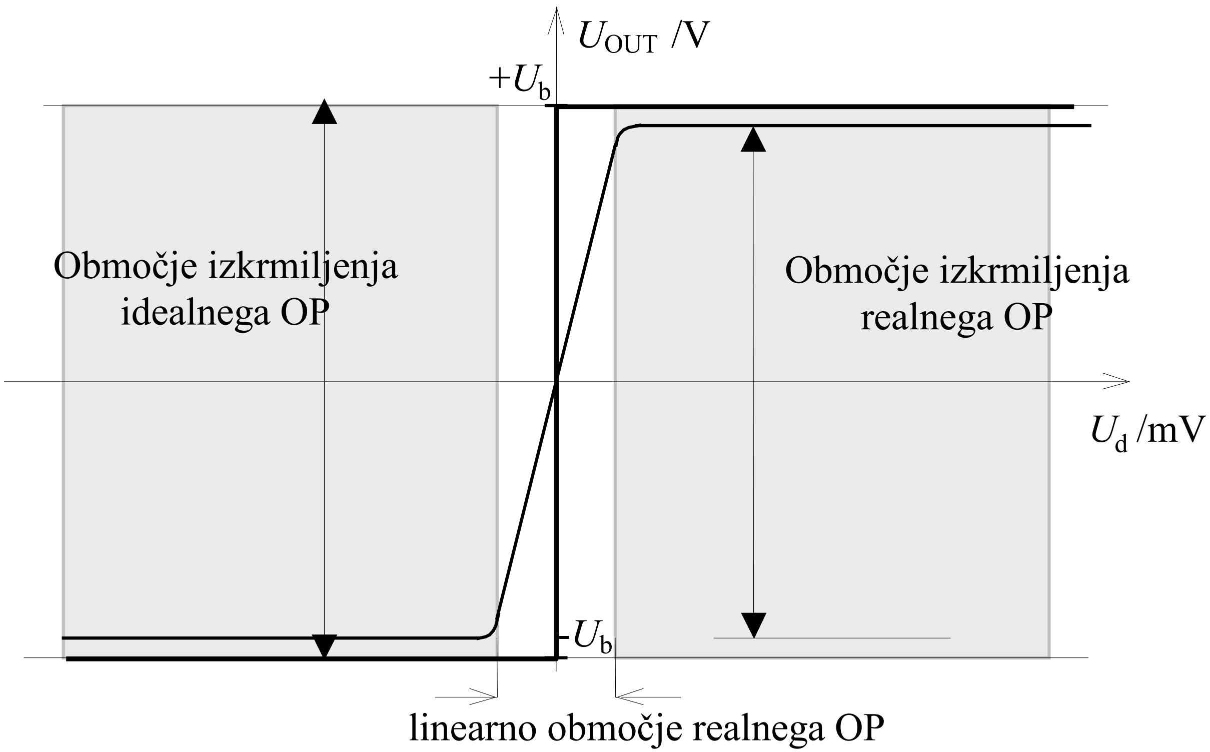
- lastnosti idealnega operacijskega ojačevalnika

lastnost	idealni OP	realni OP
ojačenje A_d	$A_d = \infty$	$A_d = 20*10^3 \ldots 10^6$
vhodna upornost r_{in}	$r_{in} = \infty$	$r_{in} = 10^6\ \Omega \ldots 10^{14}\ \Omega$
izhodna upornost r_{out}	$r_{out} = 0$	$r_{out} = 30\ \Omega \ldots$



Operacijski ojačevalnik

1. izhodna napetost ne more preseči napajalne
2. in $A_D \rightarrow \infty$ potem ...



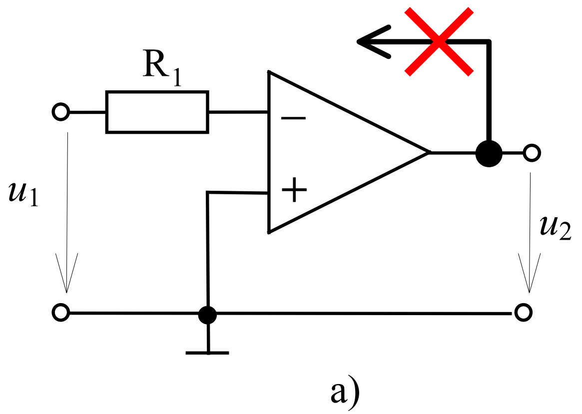
Krmilna karakteristika (transfer characteristic)

$$U_{OUT} = U_d \cdot A_d$$

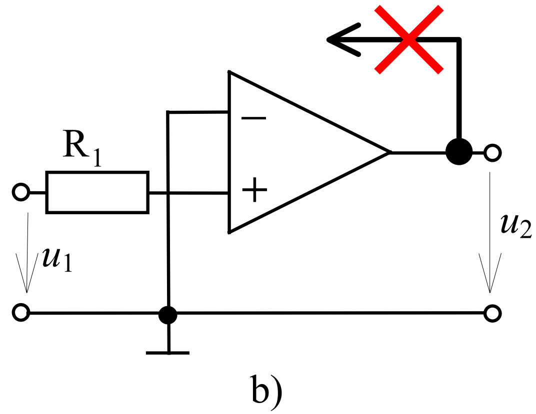
➢**če je $u_D \neq U_B$ ($-U_B$), potem velja $u_D \rightarrow 0$**

Uporaba operacijskega ojačevalnika

- redko ga uporabimo samostojno (brez elementov v povratni vezi)



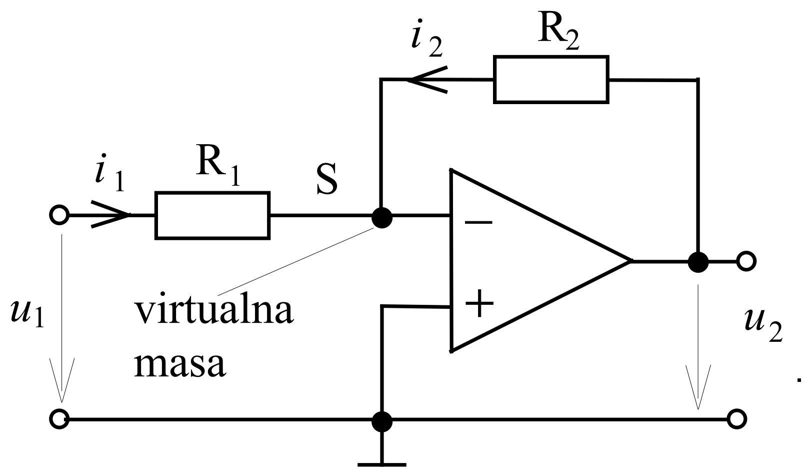
- vezja z negativno in pozitivno povratno vezjo

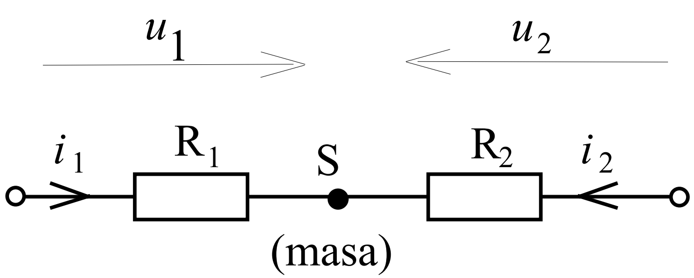


ojačevalna vezja **preklopna vezja**

Invertirajoče ojačevalno vezje

➢ če je OP idealen, velja $\mathbf{A_D} \rightarrow \infty \Rightarrow \mathbf{u_D \rightarrow 0}$ in $\mathbf{r_{VH,OP}} \rightarrow \infty \Rightarrow \mathbf{i_1 + i_2 = 0}$





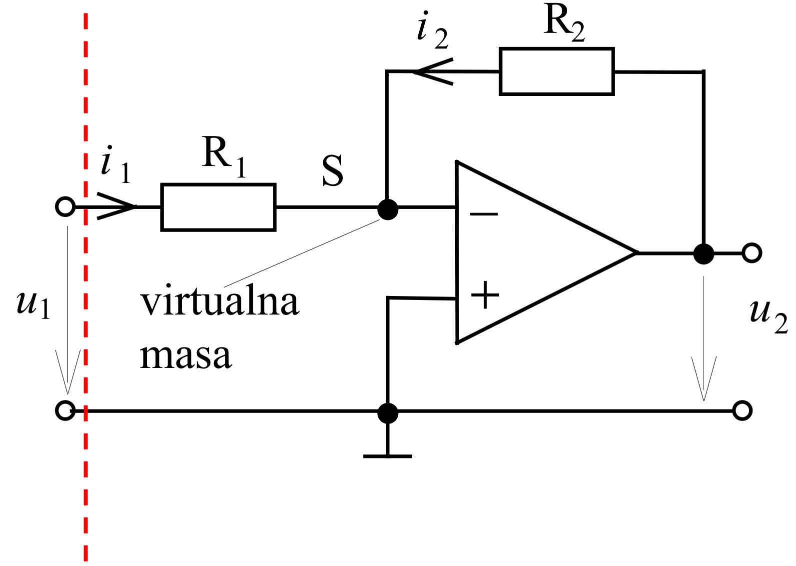
$$i_1 + i_2 = \frac{u_1}{R_1} + \frac{u_2}{R_2} = 0 \quad \Rightarrow \quad A = \frac{u_2}{u_1} = -\frac{R_2}{R_1}$$

... ojačenje vezja

Invertirajoče ojačevalno vezje

- vhodna upornost ojačevalnega vezja znaša ...

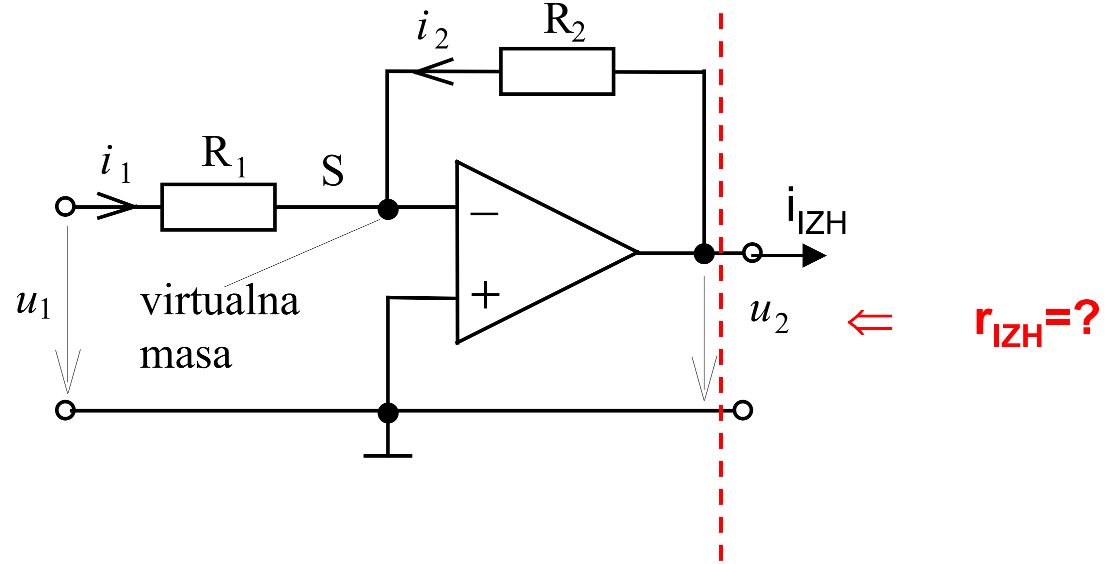
r_{VH}=? ⇒



r_{VH} $= u_1/i_1=$**R_1** **............ čeprav znaša $r_{VH,OP} \rightarrow \infty$**

Invertirajoče ojačevalno vezje

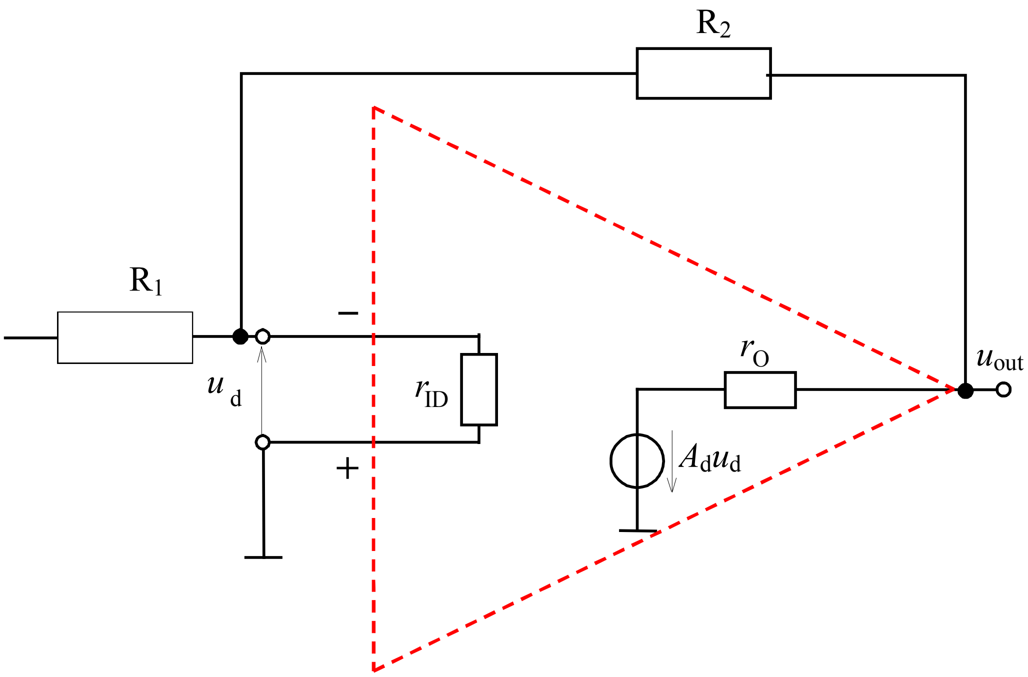
- izhodna upornost ojačevalnega vezja znaša ...



$r_{IZH} = u_2 / i_{IZH} = R_2$? ....

Invertirajoče ojačevalno vezje

➢izhodna upornost ojačevalnega <u>vezja</u> znaša ...

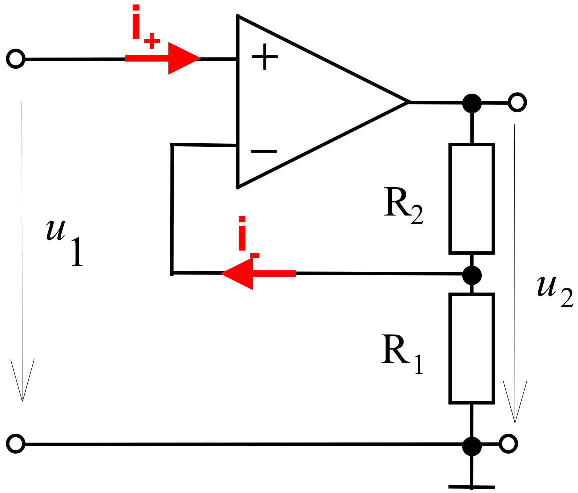


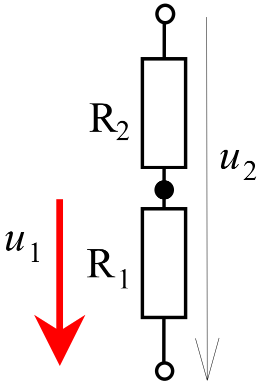
⇐ **$r_{IZH} = r_{Th}$=?**

r_{IZH}= u_2/i_{IZH}=0 ...... enako kot znaša $r_{IZH,OP} = r_O \rightarrow 0$

Neinvertirajoče ojačevalno vezje

- če je OP idealen, velja $\mathbf{A_D} \rightarrow \infty \Rightarrow$ $\mathbf{u_D \rightarrow 0}$ in $\mathbf{r_{VH,OP}} \rightarrow \infty \Rightarrow$ $\mathbf{i_- = i_+ = 0}$





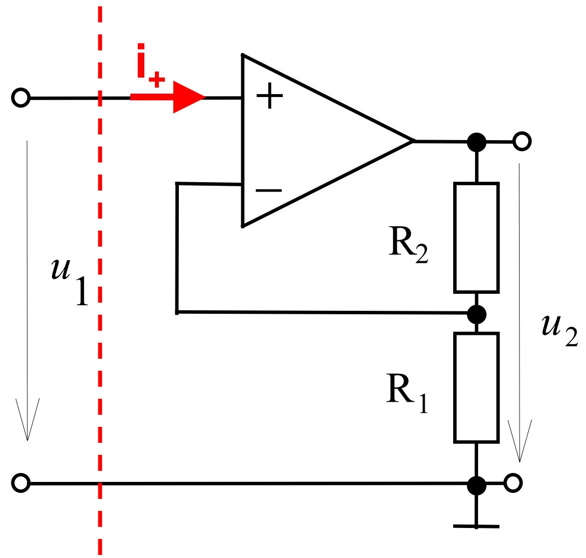
$$\frac{u_1}{R_1} = \frac{u_2}{R_1 + R_2} \quad \Rightarrow \quad A = 1 + \frac{R_2}{R_1}$$

... ojačenje vezja

Neinvertirajoče ojačevalno vezje

- vhodna upornost ojačevalnega vezja znaša ...

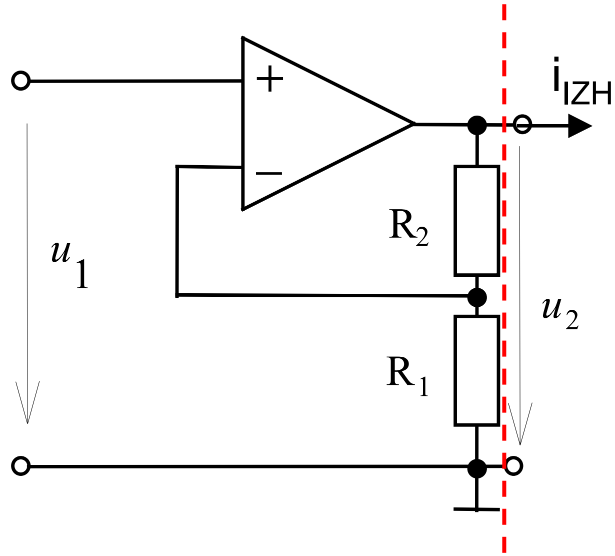
r_{VH}=? ⇒



$r_{VH} = u_1/i_1 = \infty$ .... **enako kot znaša $r_{VH,OP} \to \infty$**

Neinvertirajoče ojačevalno vezje

- izhodna upornost ojačevalnega vezja znaša ...

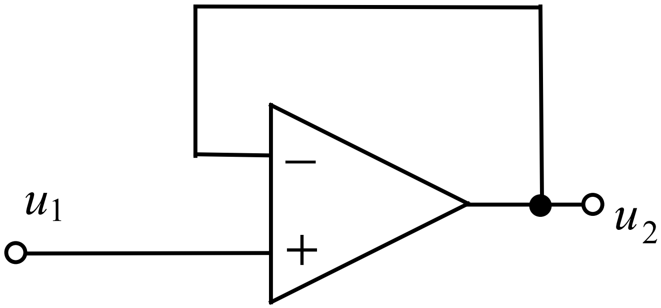


⇐ r_{IZH}=?

$r_{IZH} = u_2 / i_{IZH} = 0$ ...... **enako kot znaša $r_{IZH,OP} = r_O \to 0$**

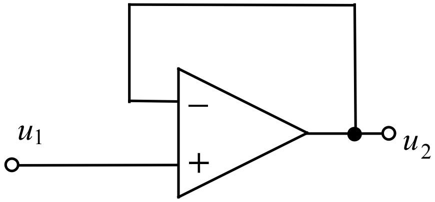
Neinvertirajoče ojačevalno vezje

➢v primeru R_2=0 in R_1=∞



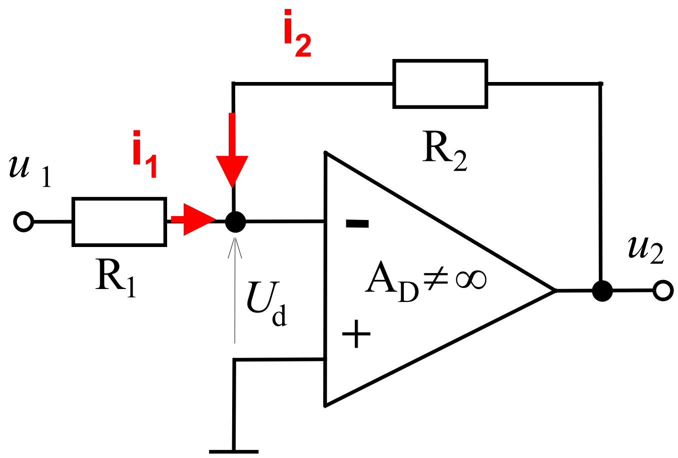
Lastnosti napetostnega sledilnika

- ojačenje je enako 1
- r_{VH}= ∞
- r_{IZH}=0



Inver.ojač.vezje-vpliv realnega A_D

- ker je $A_D \neq \infty$, velja tudi $u_D \neq 0$
- ostale lastnosti idealnega OP ostajajo v veljavi!



$i_1 + i_2 = 0$

$$\frac{u_1 + u_d}{R_1} = -\frac{u_2 + u_d}{R_2}$$

$$u_2 = A_d u_d = -A_d \left(u_1 \frac{R_2}{R_1 + R_2} + \frac{R_1}{R_1 + R_2} u_2\right)$$

$$\frac{u_2}{u_1} = -\frac{R_2}{R_1} \bullet \frac{A_d \frac{R_1}{R_2 + R_1}}{1 + A_d \frac{R_1}{R_2 + R_1}}$$

... ojačenje <u>vezja</u>

Inver.ojač.vezje-vpliv realnega A_D

- Cilj: zgraditi ojačevalno vezje z ojačenjem 100
- Izhodišče: **idealni OP**, izberemo R_1=1 kΩ

$$\frac{u_2}{u_1} = -\frac{R_2}{R_1}$$

R_1=1 kΩ

R_2=100 kΩ

A= -100

- Ocena napake: **realni OP**

$$\frac{u_2}{u_1} = -\frac{R_2}{R_1} \bullet \frac{A_d \frac{R_1}{R_2 + R_1}}{1 + A_d \frac{R_1}{R_2 + R_1}}$$

R_1=1 kΩ

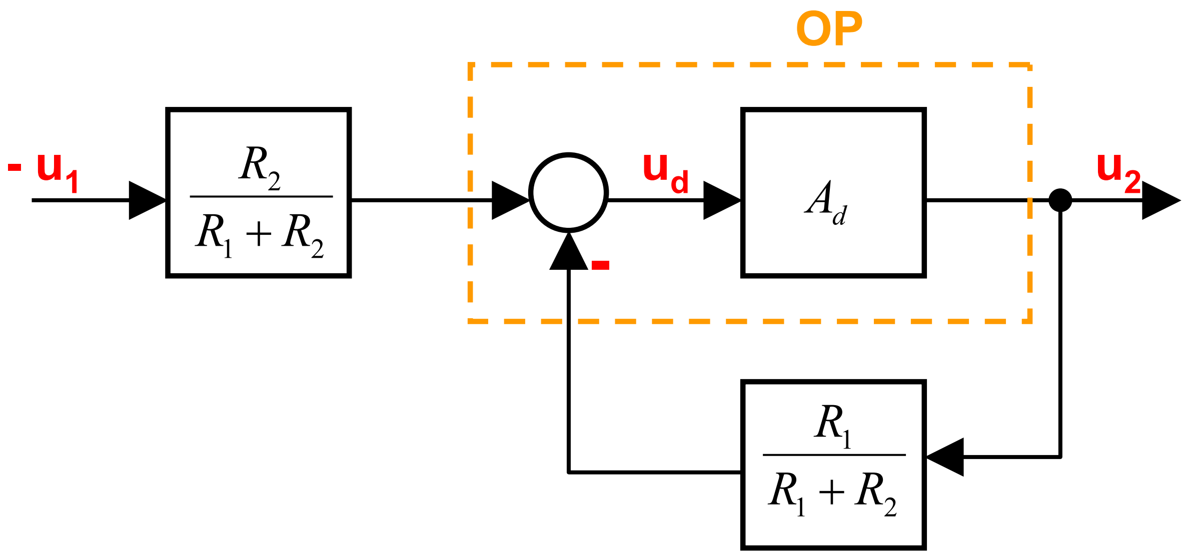
R_2=100 kΩ

A= -99,0001

Inver.ojač.vezje-vpliv realnega A_D

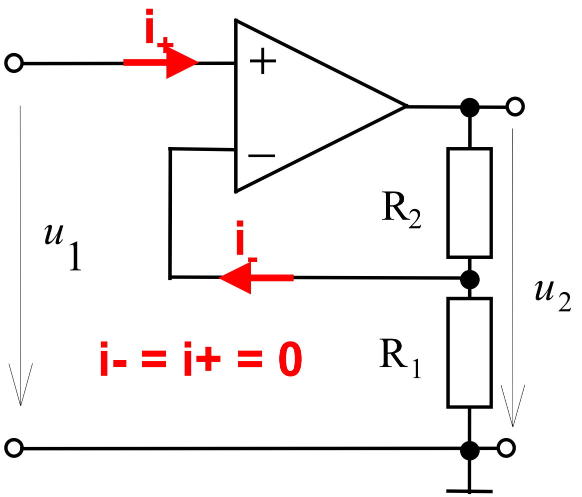
- pogled na vezje z regulacijskega stališča

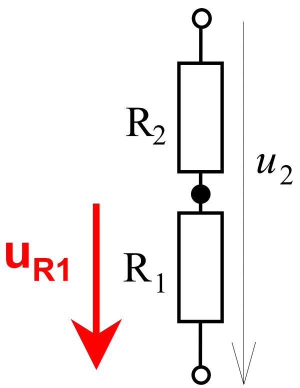
$$u_2 = A_d u_d = -A_d\left(u_1 \frac{R_2}{R_1 + R_2} + \frac{R_1}{R_1 + R_2} u_2\right)$$



Neinvertirajoče ojač.vezje-vpliv realnega A_D

- ker je $A_D \neq \infty$, velja tudi $u_D \neq 0$
- ostale lastnosti idealnega OP ostajajo v veljavi!





$u_{R1} = u_1 - u_D$

$$u_2 = A_d u_d = A_d (u_1 - u_{R1}) = A_d \left(u_1 - u_2 \frac{R_1}{R_1 + R_2}\right)$$

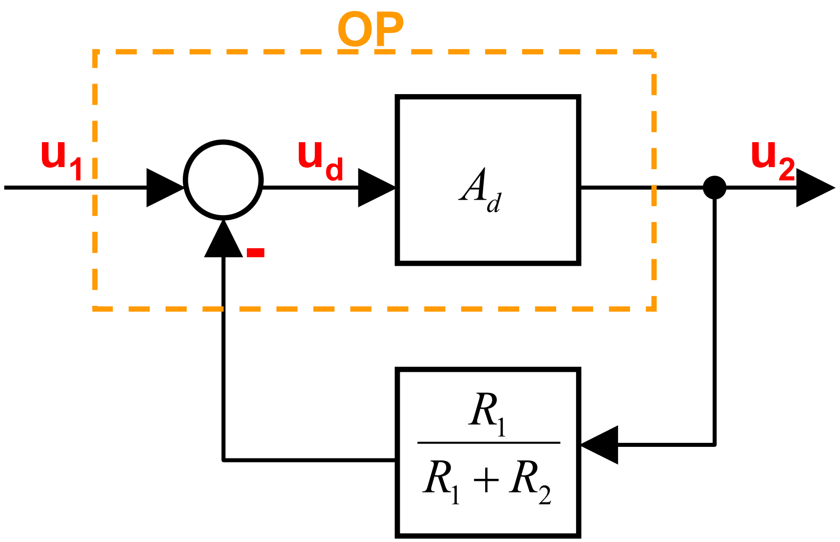
$$\frac{u_2}{u_1} = \frac{A_D}{1 + \frac{R_1}{R_1 + R_2} A_D}$$

... ojačenje <u>vezja</u>

Neinvertirajoče ojač.vezje-vpliv realnega A_D

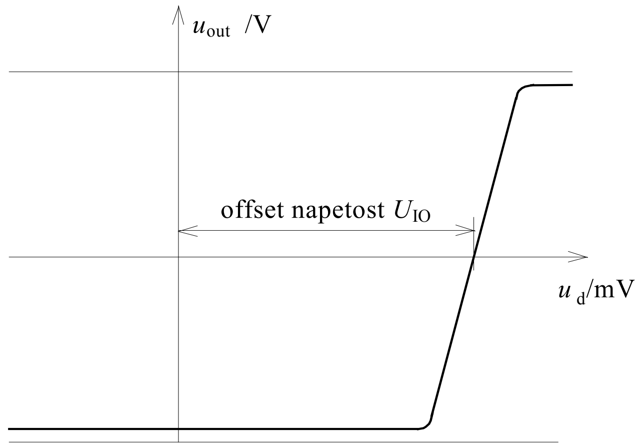
- pogled na vezje z regulacijskega stališča

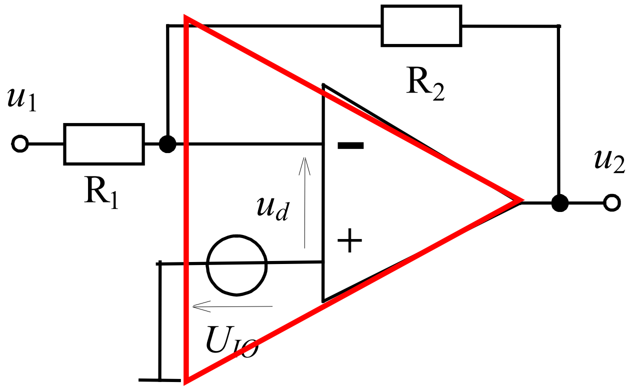
$$u_2 = A_d u_d = A_d(u_1 - u_{R1}) = A_d(u_1 - u_2 \frac{R_1}{R_1 + R_2})$$



Invert.ojač.vezje-vpliv offset-ne napetosti

- vzrok:



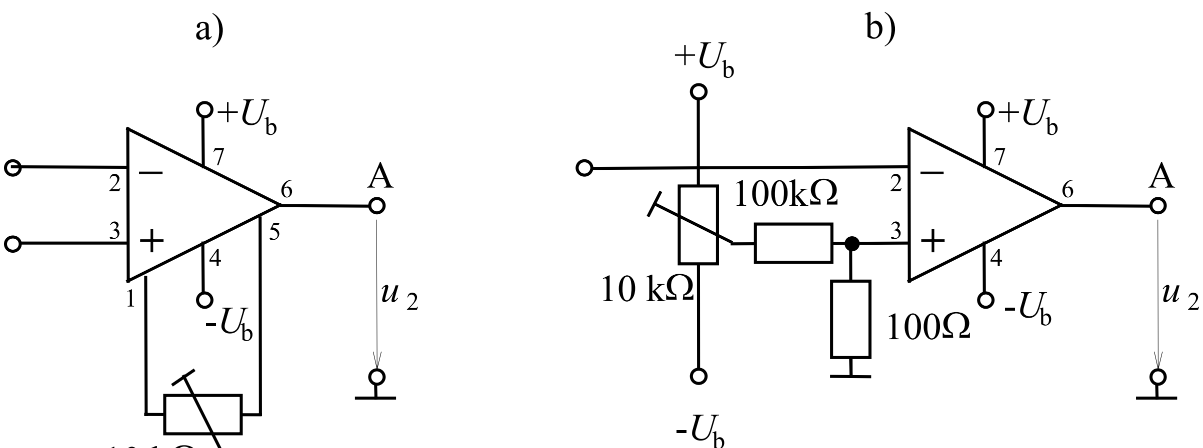


$$\frac{u_1 - U_{IO}}{R_1} + \frac{u_2 - U_{IO}}{R_2} = 0$$

$$u_2 = -u_1 \frac{R_2}{R_1} + U_{IO}\left(1 + \frac{R_2}{R_1}\right)$$

Invert.ojač.vezje-vpliv offset-ne napetosti

- kompenzacija preostale napetosti



$$\text{območje: } |U_{IO}| = U_b \frac{100\ \Omega}{100\ \text{k}\Omega}$$

$$\Delta U_{IO}(\vartheta, U_b, t) = \frac{dU_{IO}}{d\vartheta}\Delta\vartheta + \frac{dU_{IO}}{dU_b}\Delta U_b + \frac{dU_{IO}}{dt}\Delta t$$

Invert.ojač.vezje-vpliv offset-ne napetosti

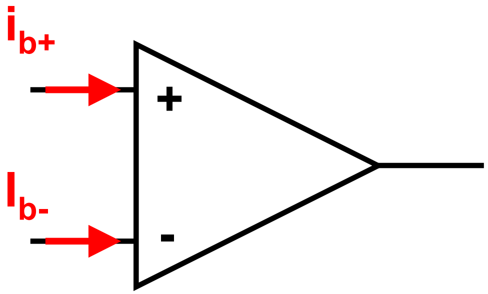
- kompenzacija preostale napetosti

$$\Delta U_{IO}(\vartheta, U_b, t) = \frac{dU_{IO}}{d\vartheta}\Delta\vartheta + \frac{dU_{IO}}{dU_b}\Delta U_b + \frac{dU_{IO}}{dt}\Delta t$$

Parameter	Bipolar	BiFET	CMOS	Chopper
U_{IO}	10 µV...7 mV	500µV...15mV	200 µV...10 mV	0,1...5 µV
temperaturni vpliv $\frac{dU_{IO}}{d\vartheta}$ (*input offset voltage drift*)	0,1....10 µV/°C	5....40 µV/°C	1....10 µV/°C	0,001... 0,005µV/°C
vpliv napaj. napetosti $\frac{dU_{IO}}{dU_b}$ (*line regulation*)	0,01....1 mV/V			
lezenje $\frac{dU_{IO}}{dt}$	0,01....1 mV/s			

Invert.ojač.vezje-vpliv mirovnega toka

- vzrok:



$$I_b = \frac{I_{b-} + I_{b+}}{2}$$

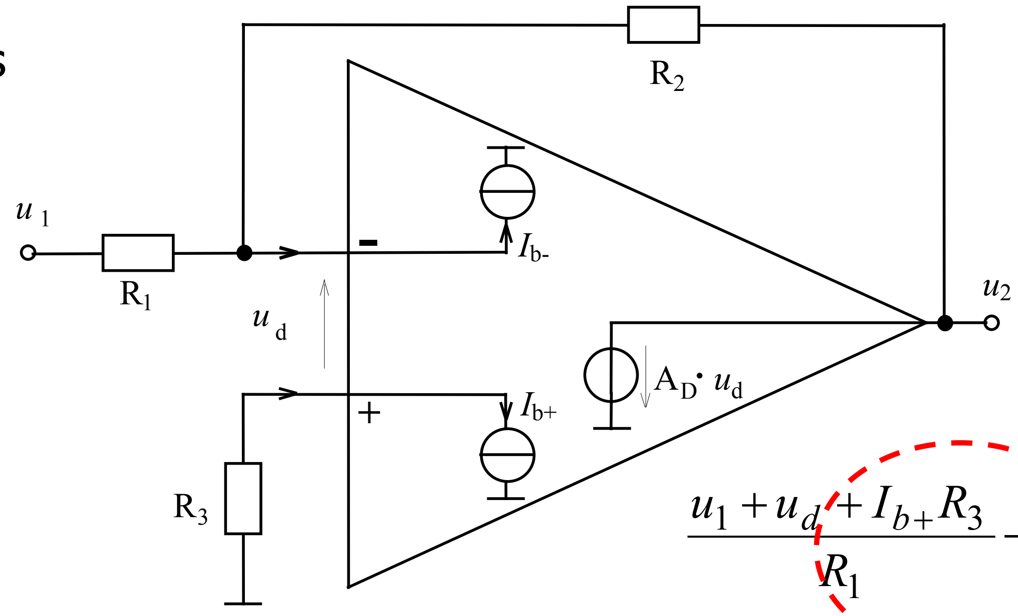
angl. input bias current

$$I_{IO} = I_{b+} - I_{b-}$$

angl. input offset current

Invert.ojač.vezje-vpliv mirovnega toka

- S



$$\frac{u_1 + u_d + I_{b+}R_3}{R_1} - I_{b-} + \frac{u_2 + u_d + I_{b+}R_3}{R_2} = 0$$

$$\frac{I_{b+}R_3}{R_1} - I_{b-} + \frac{I_{b+}R_3}{R_2} = 0$$

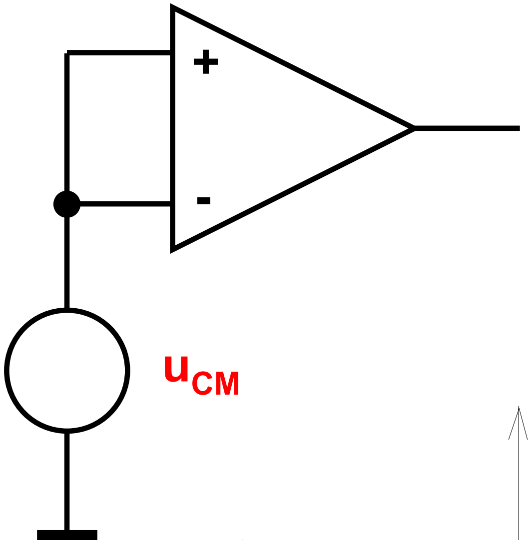
$$R_3 = \frac{I_{b-}}{I_{b+}} \cdot \frac{R_2 \cdot R_1}{R_2 + R_1}$$

$$R_3 = \frac{R_2 \cdot R_1}{R_2 + R_1}$$

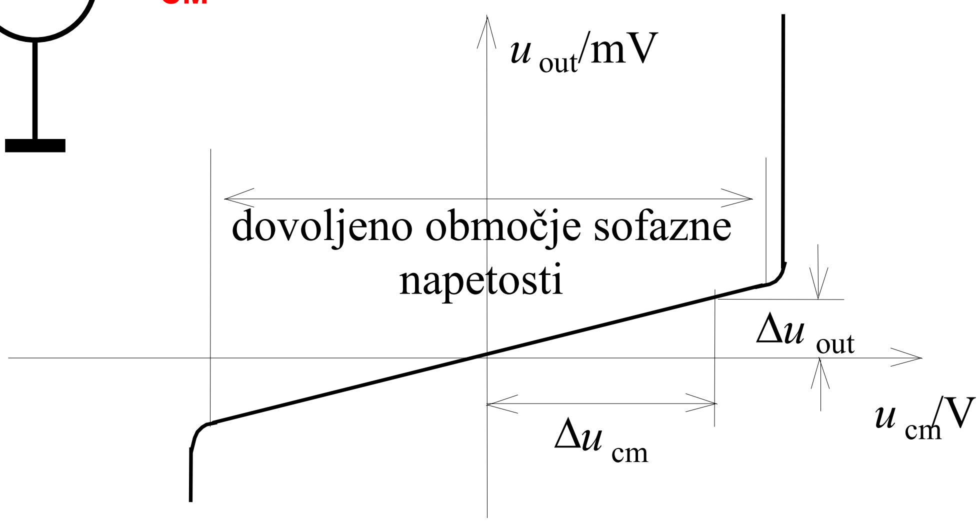
$$u_2 = -u_1 \cdot \frac{R_2}{R_1} + I_{IO}R_2$$

Invertirajoče ojač.vezje-vpliv sofaznega ojačenja

- u_{IZH} bi morala biti enaka 0, pa ni ...
- vzrok: sofazno ojačenje A_{CM}



angl. common mode gain



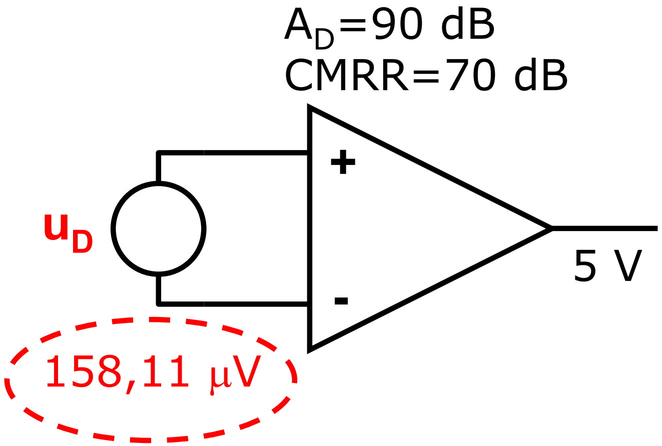
$$A_{cm} = \frac{\Delta u_{out}}{\Delta u_{cm}}$$

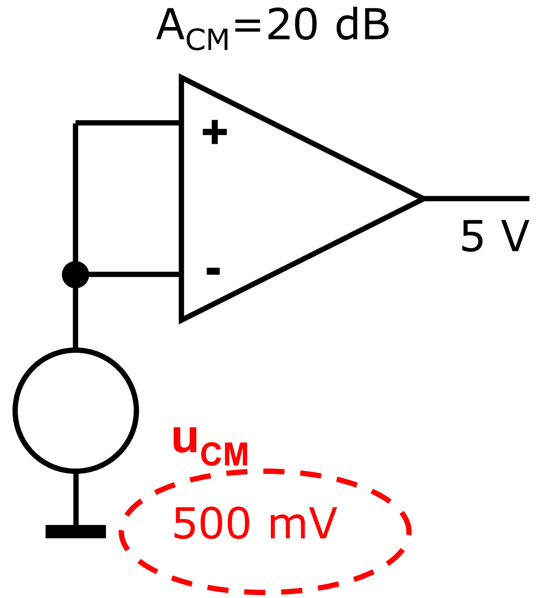
$$CMRR = 20 \cdot \log \frac{A_d}{A_{CM}}$$

angl. Common Mode Rejection Ratio

Invertirajoče ojač.vezje-vpliv sofaznega ojačenja

- primer:

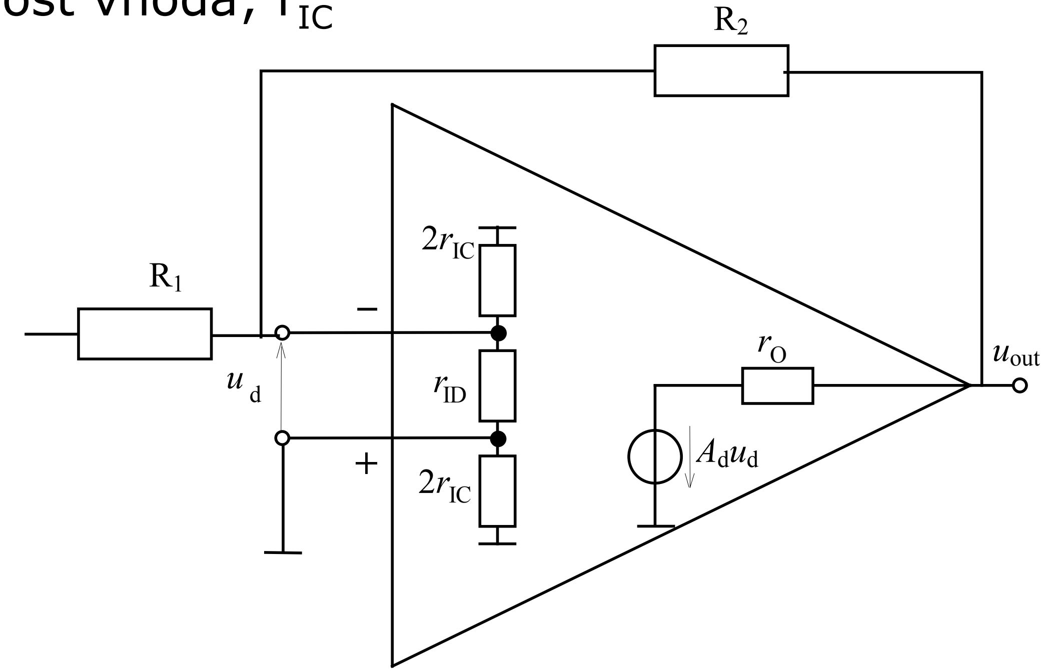




$$CMRR = 20\log\frac{A_D}{A_{CM}} = 20\log A_D - 20\log A_{CM}$$

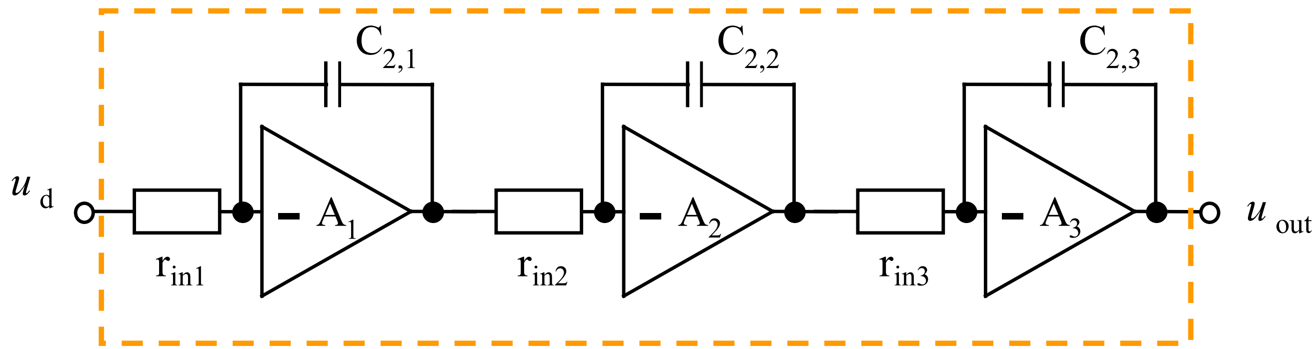
Invertirajoče ojač.vezje-vpliv končne dinamične vhodne in izhodne upornosti

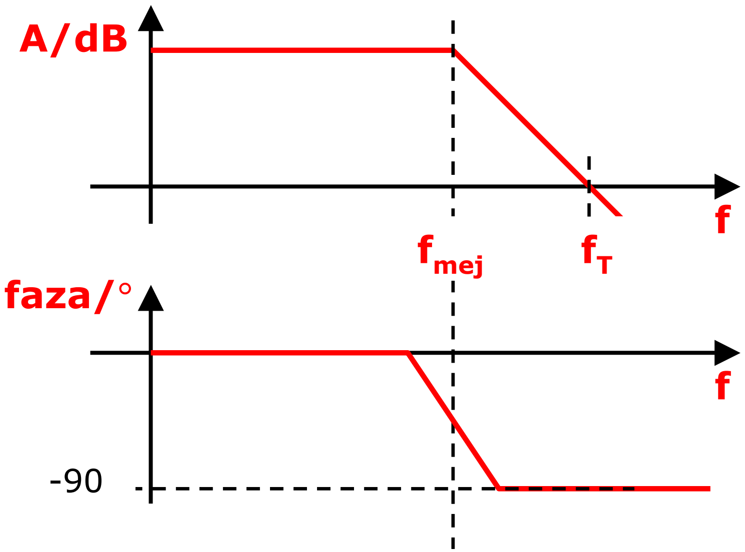
- diferenčna vhodna upornost; r_{ID} (bipol.: $10^5\Omega \div 10^6\Omega$, FET: $10^{12}\Omega \div 10^{15}\Omega$)
- vh.upornost vhoda; r_{IC}



- izh.upornost; r_O ($30\Omega \div 1k\Omega$)

OP in njegova frekvenčna karakteristika



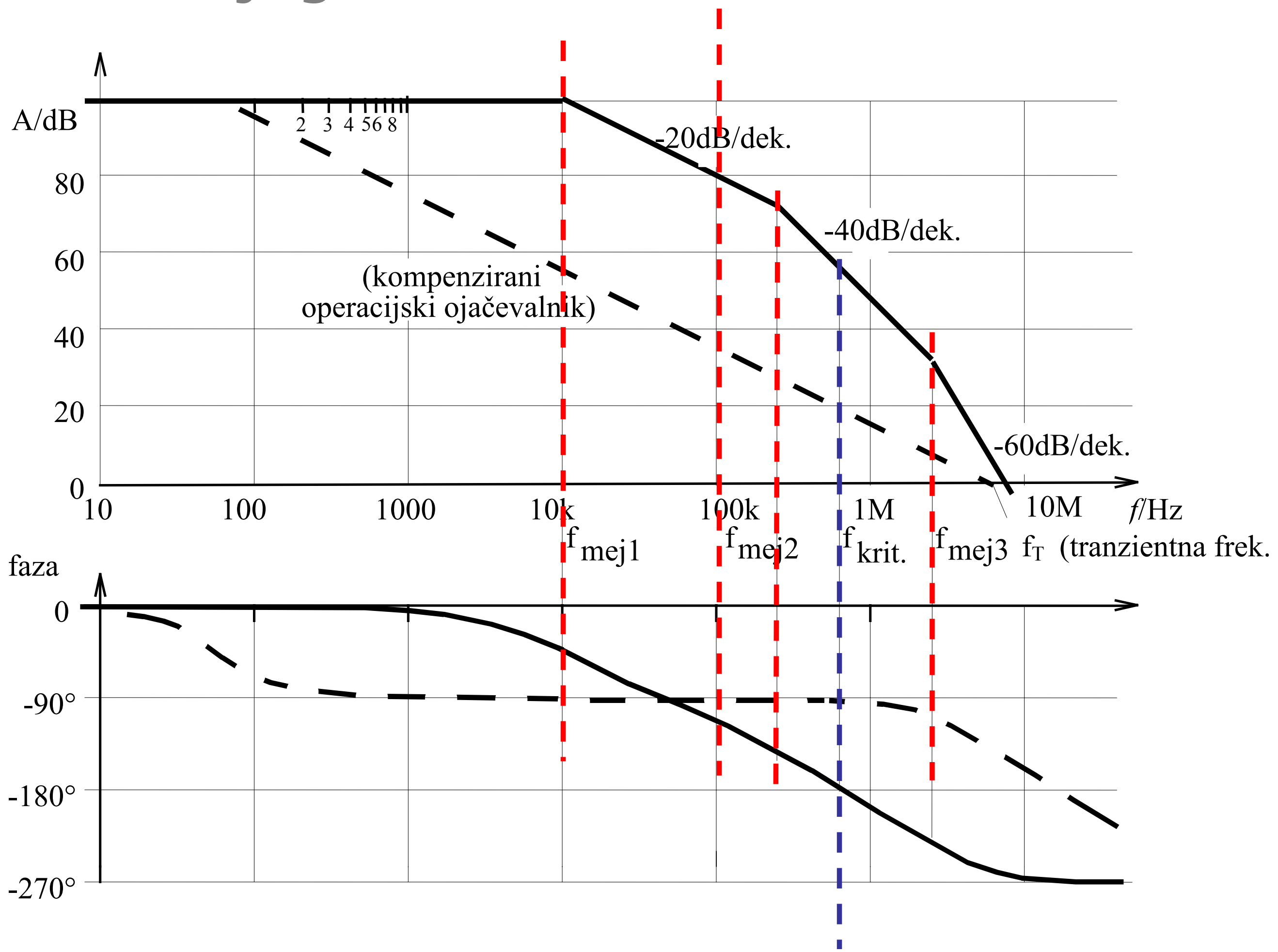


$$\frac{u_{out,i}}{u_{in,i}} = -\frac{A_i}{1 + j\omega(1 + A_i)\cdot r_{in,i}\cdot C_{2,i}}$$

$$f_{mej,i} = \frac{1}{2\pi\cdot\underline{(1 + A_i)}\cdot r_{in,i}\cdot C_{2,i}}$$

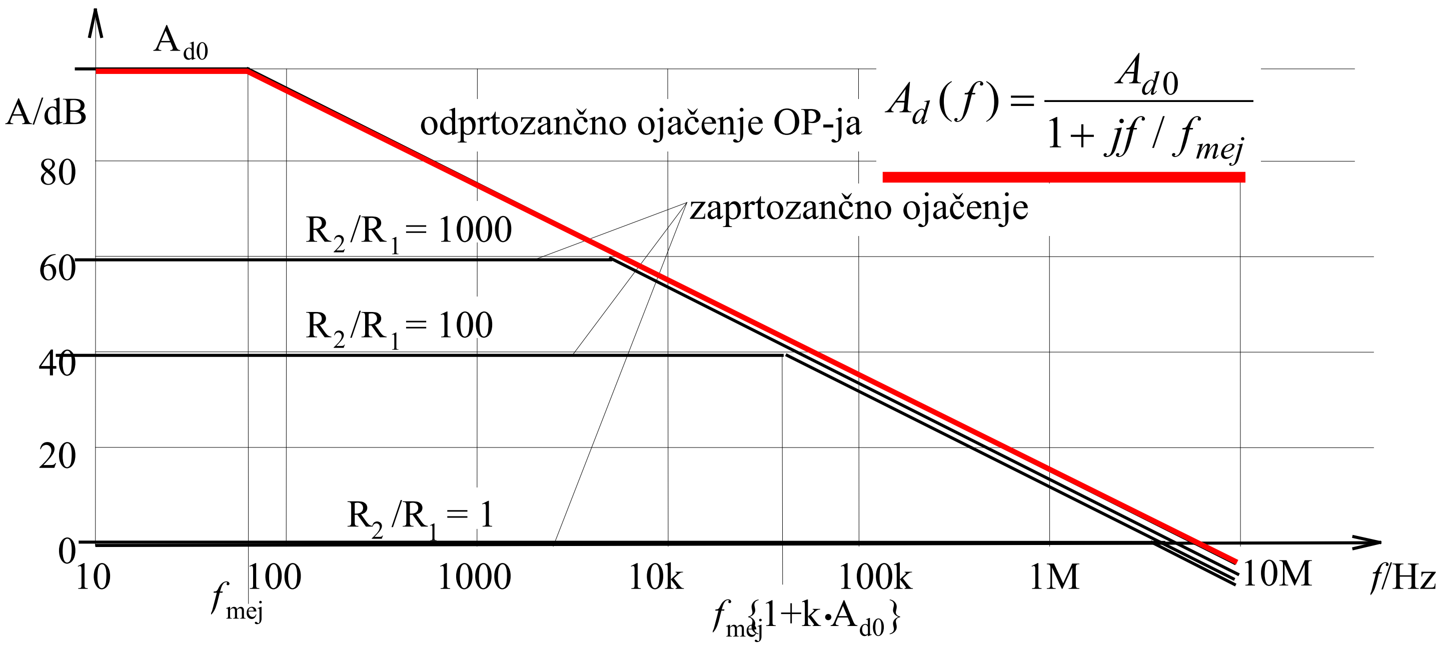
GBW (*gain bandwidth product*)

OP in njegova frekvenčna karakteristika



➢stabilnost: $A(f_{krit.}) \cdot k < 1$ npr. $\frac{R_2}{R_1} > A(f_{krit.}) - 1$

OP in njegova frekvenčna karakteristika



$$A_d(f) = \frac{A_{d0}}{1 + jf / f_{mej}}$$

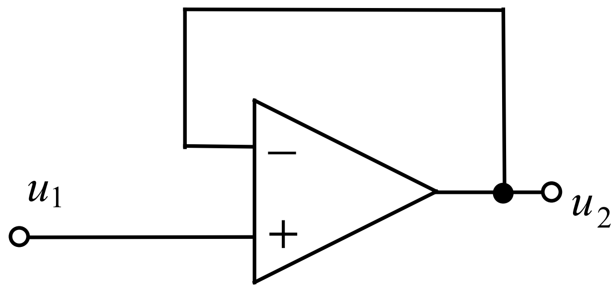
➢z ojačenjem v povratni vezi:

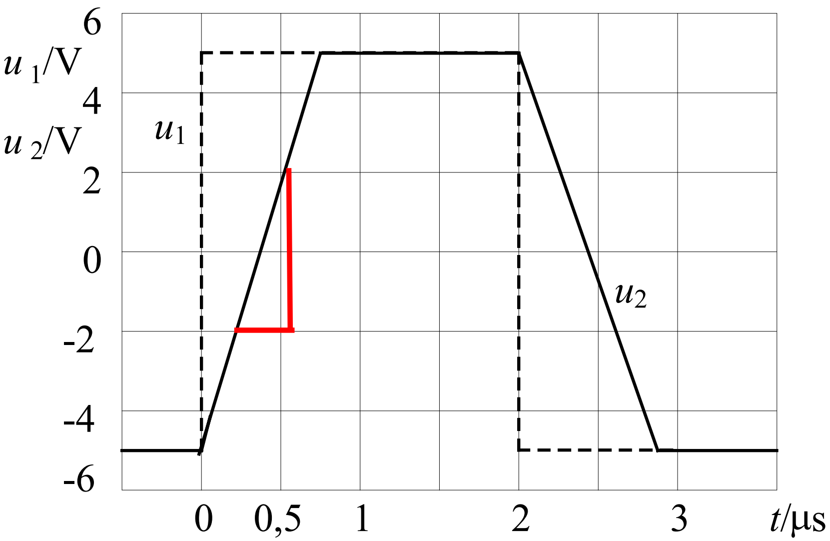
$$u_2 = \frac{A_d}{1 + k \cdot A_d} u_1$$

$$\frac{u_2}{u_1}(f) = \frac{A_d(f)}{1 + k \cdot A_d(f)} = \frac{A_{d0}}{1 + k \cdot A_{d0}} \cdot \frac{1}{1 + j \frac{f}{f_{mej}} \frac{1}{1 + k \cdot A_{d0}}}$$

OP in njegova frekvenčna karakteristika

➢ slew rate:





$$SR = \left.\frac{du_{out}}{dt}\right|_{\max}$$

OP in njegova frekvenčna karakteristika

➢slew rate: pri sinusnem vh.napetosti ...

$$\frac{du_{out}}{dt} = \frac{d(\hat{U}_{out}\sin\omega t)}{dt} = \omega\hat{U}_{out}\cos(\omega t) \qquad \text{in od tu} \qquad \left(\frac{du_{out}}{dt}\right)_{\max} = 2\pi f\hat{U}_{out}$$