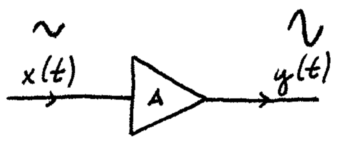
22.2.2013

I. Popačenja ojačevalnikov

spremeni se oblika signala



$y(t) = A \cdot x(t)$

Lin. vezje brez popačenj
A = konst.

v praksi imamo zakasnitve:

$y(t) = A \cdot x(t - t_0)$

zakasnitev 30 μs/cm

ČASOVNI → FREKVENČNI prostor

$Y(\omega) = A \cdot X(\omega)$ Fourier

$Y(s) = A \cdot X(s)$ Laplace

Lin. vezje brez popačenj
A realna konst.

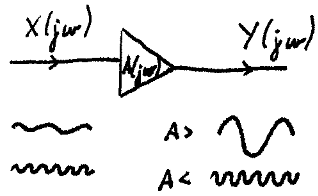
TIPI POPAČENJ:

- Linearno
- Nelinearno

1. Linearno popačenje

$Y(j\omega) = A \cdot X(j\omega)$

$A = A(j\omega)$ frekvenčno odvisen



a) Amplitudno popačenje

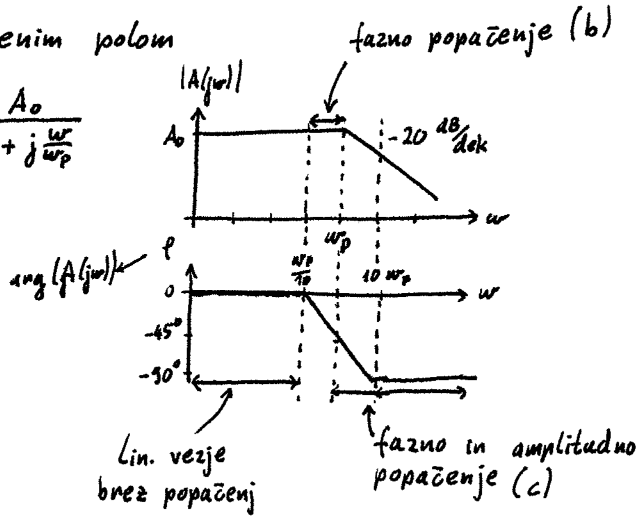
b) Fazno popačenje

c) Oboje hkrati

■ **Primer** ojač. z enim polom

$$A(j\omega) = \frac{A_0}{1 + j\frac{\omega}{\omega_p}}$$

Bodejev diagram:

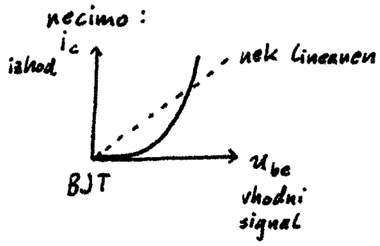


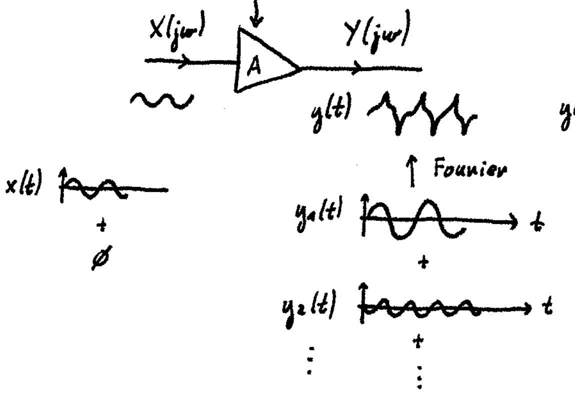
AEV - P - 3

2. Nelinearno popačenje

$$Y(j\omega) = A \cdot X(j\omega)$$

$A = A(X(j\omega))$ odvisen tudi od velikosti vhodnega signala





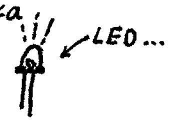
$y(t) = y_1(t) + y_2(t) + \ldots$

na izhodu pridelamo neke nove frekvence !

Kako matematično opisati nelinearnost ?

- stopnja nelinearnosti ojačevalnika

Taylorjeva vrsta !



$y = y(x)$ $\quad x = x(t)$

$x = x_0 + \Delta x$ $\quad (\Delta x = \underset{\text{izm.}}{x} - \underset{\text{enosmerna}}{x_0})$

$$y(x) = \underset{\text{Taylor}}{y(x_0 + \Delta x) =} a_0 + \underbrace{a_1 \Delta x}_{\text{linearni del}} + \underbrace{a_2 \Delta x^2 + a_3 \Delta x^3 + \ldots}_{\text{nelinearni del}} \rightarrow \text{POPAČENJE}$$

$$a_n = \frac{\frac{d^n y}{dx^n}}{n!} \qquad n = 0, 1, \ldots \infty$$

nek konkreten signal :

$\Delta x = \Delta x(t) = X \cdot \cos \omega t$

X – ampl. vh. signala

izhod : (Taylor)

$$y(x_0 + \Delta x) = a_0 + a_1 X \cdot \cos\omega t + a_2 \underbrace{X^2 \cos^2 \omega t} + a_3 \underbrace{X^3 \cos^3 \omega t} + \ldots$$

priročnik

$$X^2 \cos^2 \omega t = X^2 \cdot \frac{1}{2}(1 + \cos 2\omega t) = \frac{X^2}{2} + \frac{X^2}{2} \cos 2\omega t$$

$\frac{X^2}{2}$ – neka konstanta recimo [mV], premik delovne točke

$\cos 2\omega t$ – nova frekvenca, 2. harmonska komponenta (amplitudno popačenje)..

$$X^3 \cos^3 \omega t = X^3 \cdot \frac{1}{4}(3 \cdot \cos \omega t + \cos 3\omega t) = X^3 \cdot \frac{3}{4} \cos \omega t + \frac{X^3}{4} \cos 3\omega t$$

$\cos 3\omega t$ – 3. harmonska

AEV - P - 4

Lepši zapis izhoda:

$$y(x_0 + X\cos\omega t) = \underset{\substack{\uparrow \\ a_0\,?}}{Y_0} + \underset{\substack{\uparrow \\ \text{osn. harm.} \\ \text{komponenta}}}{Y_1\cos\omega t} + \underbrace{Y_2\cos 2\omega t + Y_3\cos 3\omega t + \dots}_{\text{višji harmoniki}}$$

do istega bi prišli preko fourierove trans.

$$Y_0 = \underset{\substack{\uparrow \\ \text{osnovna} \\ \text{DT, ko} \\ \text{ni signala}}}{a_0} + \underset{\substack{\uparrow \\ \text{spreminjanje} \\ \text{delovne točke}}}{a_2\frac{X^2}{2} + a_4\frac{3}{8}X^4 + \dots}$$

$$Y_1 = a_1 X + \frac{3}{4}a_3 X^3 + \frac{5}{8}a_5$$

$$Y_1 = a_1 X$$

$$Y_2 = \frac{a_2}{2}X^2 \leftarrow \text{popačenje raste z amplitudo!}$$

$$Y_3 = \frac{a_3}{4}X^3$$

Merilo nelinearnega popačenja

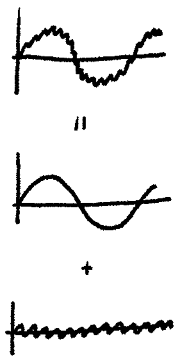
a) THD (total harmonic distortion)

(K)

$$THD = \sqrt{\frac{\sum_{n=2} Y_n^2}{\sum_{n=1} Y_n^2}} =$$

Y_n so amplitude oz. bolj pogosto efektivne vrednosti komponent izhoda

$$THD = \frac{\text{efektivna vrednost popačenega dela (VH)}}{\text{efektivna vrednost celotnega signala}}$$



$$U_{ef} = \sqrt{U_{ef1}^2 + U_{ef2}^2}$$

U_{ef1}

U_{ef2}

THD %, dB

THD odvisen od frekvence in amplitude vh. signala!

$$THD' = \frac{\sqrt{\sum_{n=2}^{\infty} Y_n^2}}{Y_1}$$

(K') najbolj pogosta

tudi za moč:

$$THD_{power} = \frac{\sum_{n=2}^{\infty} Y_n^2}{\sum_{n=1}^{\infty} Y_n^2}$$

(d)

$$THD' \doteq THD$$

$$\left(THD = \frac{THD'}{\sqrt{1 + THD'^2}} \right)$$

b) Faktorji popačenja za posamezno harmonsko komponento

$$HD_n = \frac{Y_n}{Y_1}$$

(K_n)

$$THD^* \doteq THD' = \sqrt{HD_2^2 + HD_3^2 + \dots}$$

$$HD_{power_n} = \frac{Y_n^2}{Y_1^2}$$

AEV - P - 5

28. 2. 2013

Poglejmo si primer, če imamo na vhodu seštevek dveh sinusov:

$$\Delta x(t) = X_1 \cos \omega_1 t + X_2 \cos \omega_2 t$$

izhod: $y(t) = y(X_0 + \Delta x(t)) = a_0 + a_1 \Delta x + a_2 \Delta x^2 + a_3 \Delta x^3$ ⇢ zanemarimo višje nelinearnosti

$$\Delta x^2 = X_1^2 \cos^2 \omega_1 t + X_2^2 \cos^2 \omega_2 t + 2 X_1 X_2 \underbrace{\cos \omega_1 t \cdot \cos \omega_2 t}$$

↑ razstavimo na vsote

$$\tfrac{1}{2}(1 + \cos 2\omega_1 t) \qquad \tfrac{1}{2}(1 + \cos 2\omega_2 t) \qquad \tfrac{1}{2}\left[\cos(\omega_1 - \omega_2)t + \cos(\omega_1 + \omega_2)t\right]$$

↑ neke nove komponente!

- za nelinearnost drugega reda:

  na vhod ω_1 ω_2

  na izhodu ω_1 ω_2 $2\omega_1$ $2\omega_2$ $\underbrace{\omega_1 - \omega_2 \quad \omega_1 + \omega_2}$

  intermodulacijske komponente popačenja

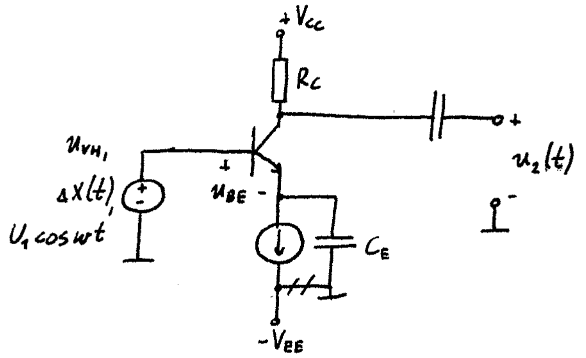
  $$IMD = \frac{Y_{IM}}{Y_1}$$

- za nelinearnost tretjega reda: (brez drugega reda)

  na izhodu ω_1 ω_2 $3\omega_1$ $3\omega_2$ $2\omega_1 + \omega_2$ $2\omega_2 + \omega_1$ $2\omega_1 - \omega_2$ $2\omega_2 - \omega_1$

Popačenja tranzistorskih ojačevalnih stopenj

1) Bipolarni tranzistor CE



$u_2 \propto i_c \propto u_{VH}$

$$i_c = I_{ES}\, e^{\frac{u_{BE}}{U_T}} \; ; \quad U_T = 25{,}66 \text{ mV} \quad (24{,}8\,^\circ\text{C})$$

$$u_{BE} = U_{BE0} + \Delta x(t) = U_{BE0} + U_1 \cos \omega t$$

$$i_c = I_{ES}\, e^{\frac{U_{BE0} + U_1 \cos \omega t}{U_T}} = I_{ES}\, e^{\frac{U_{BE0}}{U_T}} \cdot e^{\frac{U_1 \cos \omega t}{U_T}}$$

mat. priroč. ↓ razvijemo!

$$e^{\frac{U_1 \cos \omega t}{U_T}} = I_0\left(\frac{U_1}{U_T}\right) + 2 \sum_{n=1}^{\infty} I_n\left(\frac{U_1}{U_T}\right) \cos n\omega t$$

$I_n \rightarrow$ modificirane Besselove funkcije prve vrste n-tega reda, argument $\frac{U_1}{U_T}$

AEV - P - 6

$$\left[\; u_{BE} = U_{BE} + \underset{\uparrow \atop U_{be}\cos\omega t}{u_{be}} \right.$$

vstavimo:

$$i_c = I_{ES}\, e^{\frac{U_{BE0}}{U_T}} \cdot \left[J_0\!\left(\frac{U_1}{U_T}\right) + 2\sum_{n=1}^{\infty} \overset{J_n\left(\frac{U_1}{U_T}\right)}{\cancel{\left(\frac{U_1}{U_T}\right)}} \cos n\omega t \right]$$

- enosmerna komponenta:

$$I_c = I_{ES}\, e^{\frac{U_{BE0}}{U_T}} J_0\!\left(\frac{U_1}{U_T}\right) \doteq \underset{\text{konst T.V. tokovni vir}}{I_{EE}}$$

$$U_{BE0} = U_T \cdot \ln \frac{I_{EE}}{I_{ES}\cdot J_0\left(\frac{U_1}{U_T}\right)}$$

$$U_{BE0} = \underbrace{U_T \cdot \ln \frac{I_{EE}}{I_{ES}}}_{U_{BE}\text{ brez vhodnega signala}} - \underbrace{U_T \ln J_0\!\left(\frac{U_1}{U_T}\right)}_{\text{vpliv vhodnega signala na delovno točko},\ \Delta U_{BE0}}$$

npr $I_{EE} = 2\,mA$

$U_1 = 2.5\,mV,\ 25\,mV,\ 250\,mV$

$(U_T \approx 25\,mV)$

$\Delta U_{BE0} = -6{,}25\,\mu V$

$\Delta U_{BE0} = -5{,}9\,mV$

$\Delta U_{BE0} = -198\,mV$

(30% od 700mV)

pogosto se s spremembo delovne točke spremeni tudi ojačanje!

- prva harmonska komponenta:

$$\overset{\text{amplituda}}{Y_1} = I_{c1} = 2 I_{EE} \frac{J_1\left(\frac{U_1}{U_T}\right)}{J_0\left(\frac{U_1}{U_T}\right)}$$

$$|U_{izh}|_1 = R_c I_{c1} = 2 R_c I_{EE} \frac{J_1\left(\frac{U_1}{U_T}\right)}{J_0\left(\frac{U_1}{U_T}\right)}$$

$$/\!/ ?$$

$$U_{izh} = U_{VH} \cdot g_m \cdot R_c$$

- višje harmonske komponente:

$$Y_n = I_{cn} = 2 I_{EE} \frac{J_n\left(\frac{U_1}{U_T}\right)}{J_0\left(\frac{U_1}{U_T}\right)}$$

$$|U_{izh}|_n = 2 R_c I_{EE} \frac{J_n\left(\frac{U_1}{U_T}\right)}{J_0\left(\frac{U_1}{U_T}\right)}$$

<u>faktorji popačenja:</u>

$$HD_n = \frac{Y_n}{Y_1} = \frac{I_{cn}}{I_{c1}} = \frac{U_{izh\,n}}{U_{izh\,1}} \overset{\text{vstavimo}}{=} \frac{J_n\left(\frac{U_1}{U_T}\right)}{J_1\left(\frac{U_1}{U_T}\right)}$$

$$HD_2 = \dots$$

za $\frac{U_1}{U_T} \ll 1$

$$HD_n = \frac{1}{n!}\left(\frac{1}{2}\frac{U_1}{U_T}\right)^{n-1}$$

neodvisen od delovne točke

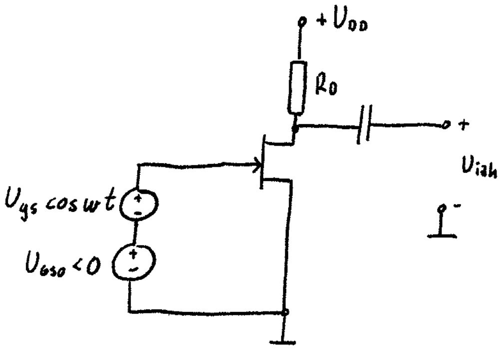
$$HD_2 = \dots = \frac{1}{4}\frac{U_1}{U_T} \rightarrow U_1 = 4 U_T HD_2 =$$

$$U_1 = 1.02\,mV$$

če HD pod 1% popačenje ni slišno

AEV - P - 7

2) Unipolarni tranzistor J-FET



$$i_D = \frac{I_{DSS}}{U_P^2}\left(u_{gs} - U_P\right)^2$$

$$u_{GS}(t) = U_{GS0} + U_{gs}\cos \omega t$$

$$i_D = \frac{I_{DSS}}{U_P^2}\left(U_{GS0} + U_{gs}\cos\omega t - U_P\right)^2$$

$$i_D = \frac{I_{DSS}}{U_P^2}\left[\left(U_{GS0} - U_P\right)^2 + 2\left(U_{GS0} - U_P\right)U_{gs}\cos\omega t + U_{gs}^2\cos^2\omega t\right]$$

U_1 U_1

amplituda vhodnega signala

$$i_D = \frac{I_{DSS}}{U_P^2}\left[\underbrace{\left(U_{GS0} - U_P\right)^2 + \frac{1}{2}U_1^2}_{\text{enosm. komponenta}} + \underbrace{2\left(U_{GS0} - U_P\right)U_1\cos\omega t}_{\text{osn. harmonska}} + \underbrace{\frac{1}{2}U_1^2\cos 2\omega t}_{\text{druga harmonska}}\right]$$

višjih harmonikov ni

popačenje:

$$HD_2 = \frac{Y_2}{Y_1} = \frac{I_{d2}}{I_{d1}} = \frac{\frac{1}{2}U_1^2}{2\left(U_{GS0} - U_P\right)U_1} = \frac{U_1}{4\left(U_{GS0} - U_P\right)}$$

primer

$U_{GS0} = \frac{U_P}{2}$ (pogosto v praksi)

$$HD_2 = \frac{-U_1}{2U_P}$$

vzamemo $U_P = -4\,V$

$U_{GS0} = -2\ V$

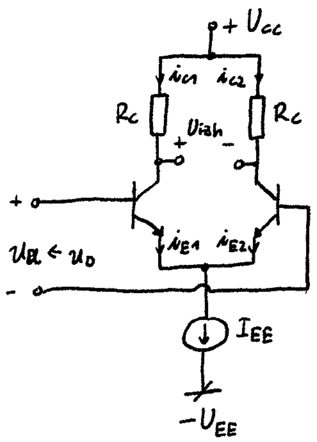
$HD_2 \leq 1\,\%$

$U_1 \doteq 80\ mV$

višji harmoniki nastanejo, če vzamemo realno enačbo:

$$i_D = \frac{I_{DSS}}{U_P^2}\left(u_{gs} - U_P\right)^{2-\gamma}$$

3) Diferencialni ojačevalnik z BJT



$$u_D = u_{BE1} - u_{BE2}$$

$$i_{E1} \doteq i_{C1} = I_{ES}\, e^{\frac{u_{BE1}}{U_T}}$$

$$i_{C2} = I_{ES}\, e^{\frac{u_{BE2}}{U_T}}$$

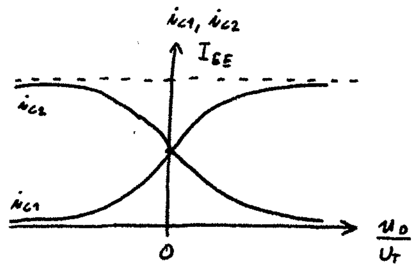
$$i_{E1} + i_{E2} = I_{EE}$$

$$i_{C1} + i_{C2} = I_{EE}$$

$$th = \frac{e^x - e^{-x}}{e^x + e^{-x}}$$

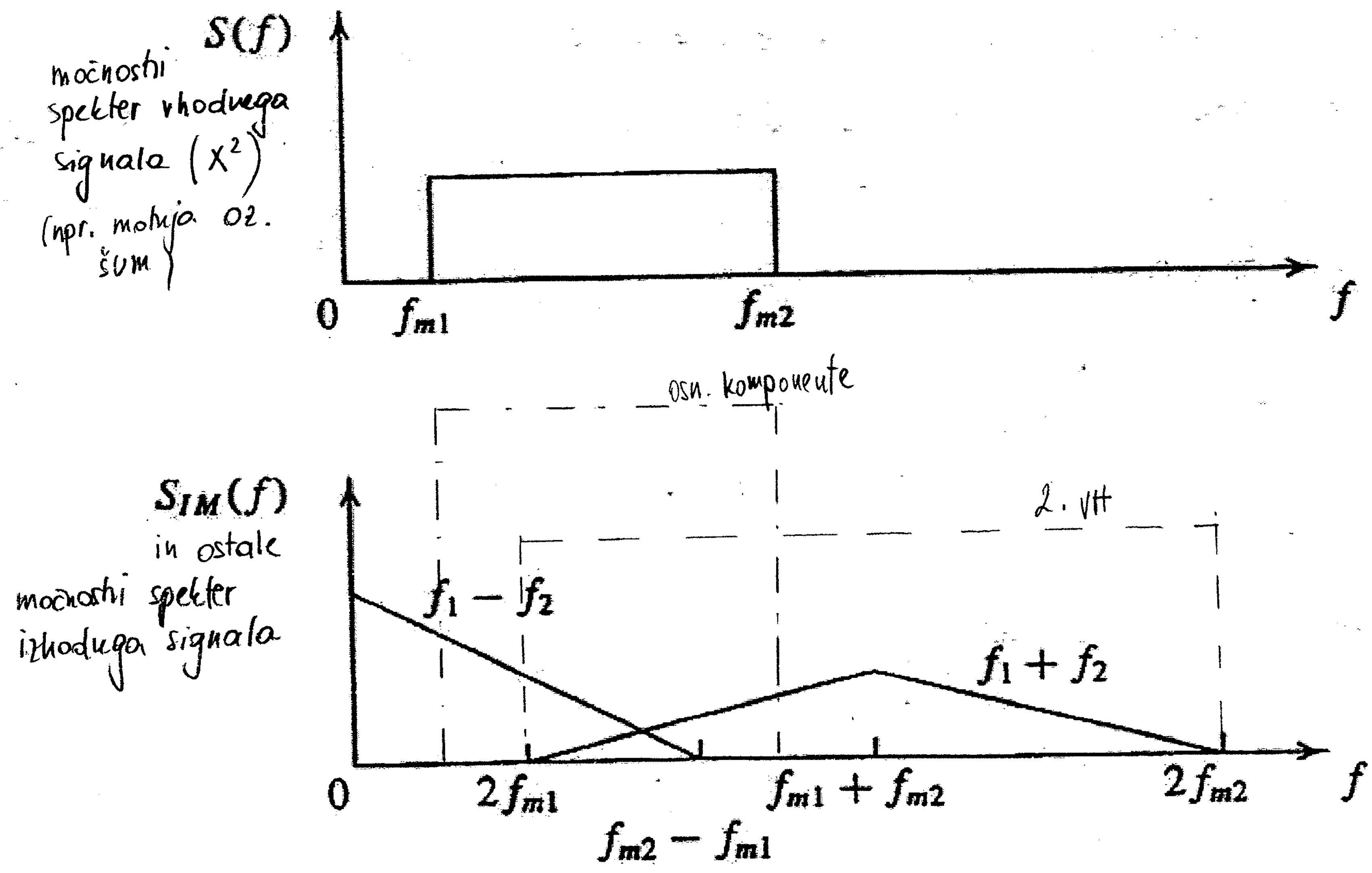
$$i_{C1} = \frac{I_{EE}}{2}\left(1 + th\frac{u_D}{2U_T}\right)$$

$$i_{C2} = \frac{I_{EE}}{2}\left(1 - th\frac{u_D}{2U_T}\right)$$



$$u_{izh} = R_C\left(i_{C2} - i_{C1}\right)$$

Popačenje 2. reda



Slika 1.17 – Spekter vhodne motnje in intermodulacijskih motenj zaradi popačenja drugega reda + ostalih komponent (– – –)

AEV - P - 8

$$u_{izh} = -R_C I_{EE}\, th\left(\frac{u_D}{2U_T}\right)$$

$th \rightarrow$ Taylor

$$th\left(\frac{u_D}{2U_T}\right) = \frac{u_D}{2U_T} - \frac{\left(\frac{u_D}{2U_T}\right)^3}{3} + \frac{2\left(\frac{u_D}{2U_T}\right)^5}{15} - \dots$$ lihe potence

kje so tle vezja? :)

npr.

$u_d = U_1 \cos \omega t$

$$th\left(\frac{U_1}{2U_T}\cos\omega t\right) = \frac{U_1}{2U_T}\cos\omega t - \frac{1}{3}\left(\frac{U_1}{2U_T}\cos\omega t\right)^3 + \frac{2}{15}\left(\frac{U_1}{2U_T}\cos\omega t\right)^5 - \dots$$

$$= \frac{U_1}{2U_T}\cos\omega t - \frac{1}{3}\left(\frac{U_1}{U_T}\right)\cdot\frac{1}{8}\cdot\frac{1}{4}\left(\cos 3\omega t + 3\cos\omega t\right) + \dots$$

$Y_1 \doteq \frac{U_1}{2U_T}$

$Y_3 \doteq \left(\frac{U_1}{2U_T}\right)^3 \frac{1}{3}\cdot\frac{1}{8}\cdot\frac{1}{4}$

$Y_2 = 0$

$HD_2 = 0$ $\qquad HD_3 = \frac{Y_3}{Y_1} = \left(\frac{U_1}{U_T}\right)^2\cdot\frac{1}{48}$

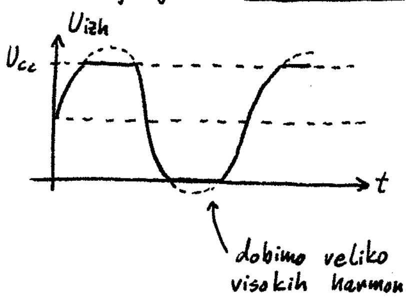
$HD_3 \doteq 1\%$

$U_1 \doteq 18\ mV$

7.3.2013

unipolarni manjše popačenje kot BJT
diferencialni majhno popačenje
negativna povratna zanka tudi lahko zmanjša popačenje

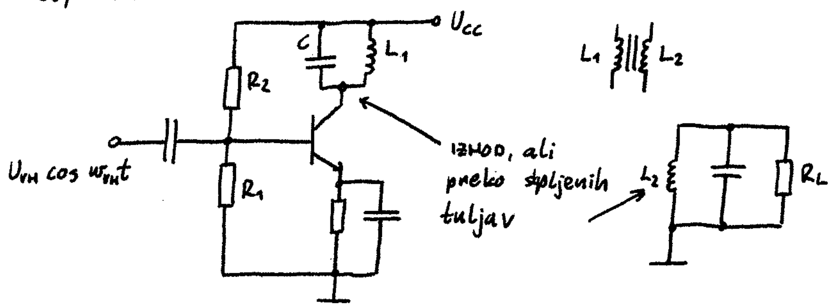
Izkrmiljenje na izhodu

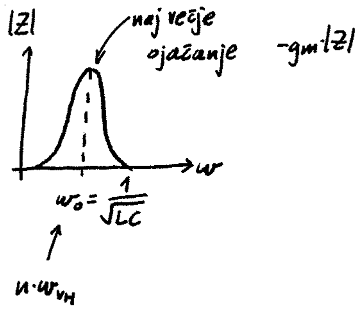


Popačenje lahko tudi uporabimo!
(naslednja stran)

AEV - P - ~~10~~ 9

a) Frekvenčni množilnik z BJT





na ojačevalniku nastanejo višji harmoniki, ojačamo jih preko LC nihajnega kroga

če $w_0 = w_{vh}$ dobimo selektiven ojačevalnik (za eno frekvenco)

b) Frekvenčni mešalnik (mešalnik signalov)

$$U_1 \cos w_1 t + U_2 \cos w_2 t \xrightarrow[\text{MOSFET}]{\text{JFET}} U_1^2 \cos^2 w_1 t + U_2^2 \cos^2 w_2 t + 2 U_1 U_2 \cos w_1 t \cdot \cos w_2 t$$

- $U_1^2 \cos^2 w_1 t \to 2w_1$
- $U_2^2 \cos^2 w_2 t \to 2w_2$
- $\to (w_1 - w_2)$ frekv. prestavljeno dol
- $\to (w_1 + w_2)$ -II- gor

Primer:

Imamo ojačevalnik z osnovnim ojačanjem $A=100$, na vhod damo signal velikosti $10\ mV_{RMS}$ in frekvence 1 kHz. Na izhodu poleg osnovne komponente s spektralnim analizatorjem zaznamo še naslednje komponente:

- 2 kHz, $100\ mV_{RMS}$
- 3 kHz, $10\ mV_{RMS}$

Določite popačenje!
THD, THD', HD, THD_{pow}, THD'_{pow}, HD_{pow}

$$THD = \sqrt{\frac{\sum_{n=2}^{\infty} Y_n^2}{\sum_{n=1}^{\infty} Y_n^2}} = \sqrt{\frac{0.01\ V^2 + 0.0001\ V^2}{1V^2 + 0.01V^2 + 0.0001\ V^2}} = 0.0999 = \underline{\underline{9.99\ \%}}$$

$$THD' = \sqrt{\frac{\sum_{n=2}^{\infty} Y_n^2}{Y_1^2}} = \sqrt{\frac{0.01V^2 + 0.0001V^2}{1V^2}} = 0.1005 = \underline{\underline{10.05\ \%}}$$

$$HD_2 = \frac{Y_2}{Y_1} = 0.1 = \underline{\underline{10\%}}$$

$$HD_3 = \frac{Y_3}{Y_1} = 0.01 = \underline{\underline{1\%}}$$

$$THD_{pow} = \frac{\sum_{n=2}^{\infty} Y_n^2}{\sum_{n=1}^{\infty} Y_n^2} = THD^2 = 0.0099 = \underline{\underline{0.9\ \%}}$$

$$THD'_{pow} = THD'^2 = \underline{\underline{1.1\ \%}}$$

$$HD_{2pow} = HD_2^2 = \underline{\underline{1\%}}$$

$$HD_{3pow} = HD_3^2 = \underline{\underline{0.01\%}}$$

Primer:

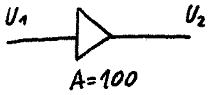
Ojačevalnik z BJT, $A_u = 100$.

a) z eno stopnjo, $A = 100$

b) z dvema stopnjama, $A = 10\cancel{000}$

Oceni faktorje popačenja (HD_2, HD_3) za oba primera. Vhodni signal ima amplitudo 2 mV.

a)



$$\frac{U_1}{U_T} = 0.0779 \ll 1$$

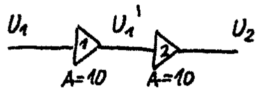
sledi aproksimacija za besselove fje če $x = \frac{U_1}{U_T} \ll 1$

HD_2

$$\frac{Y_2}{Y_1} = \frac{J_2\left(\frac{U_1}{U_T}\right)}{J_1\left(\frac{U_1}{U_T}\right)} = \frac{1}{4}\frac{U_1}{U_T} = \underline{1.95\,\%}$$

$$HD_3 = \frac{J_3}{J_1} = \frac{1}{24}\left(\frac{U_1}{U_T}\right)^2 = \underline{0.025\,\%}$$

b)



$U_1' = 20\,mV$

1. isto kot a) primer $HD_2 = \underline{1.95\,\%}$, $HD_3 = \underline{0.025\,\%}$

2. $\frac{U_1'}{U_T} = \frac{20\,mV}{25.66\,mV} = 0.779 < 1$

drugа aproksimacija za besselove fje če $x < 1$

$$J_1 = \frac{U_1'}{U_T}\cdot\frac{1}{2}\left(1 + \frac{\left(\frac{U_1'}{U_T}\right)^2}{8}\right)$$

$$J_2 = \left(\frac{U_1'}{U_T}\right)^2\cdot\frac{1}{8}\left(1 + \frac{\left(\frac{U_1'}{U_T}\right)^2}{12}\right)$$

$$J_3 = \left(\frac{U_1'}{U_T}\right)^3\cdot\frac{1}{48}\cdot\ldots$$

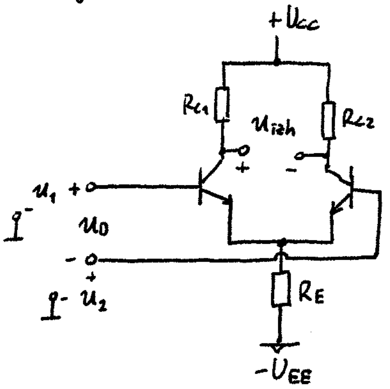
$$HD_2 = \frac{J_2}{J_1} = \underline{19.3\,\%}$$

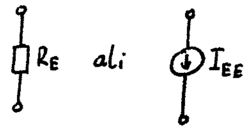
$$HD_3 = \ldots = \underline{2.4\,\%}$$

II. Diferencialni ojačevalniki

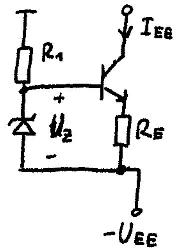
- ojačujemo samo diferencialno komponento
- preprosta izvedba povratne vezaje
- manjše popačenje kot BJT / MOSFET
- manjša T občutljivost, občutljivost od nap. napetosti

• Stopnja z NPN tranzistorji:



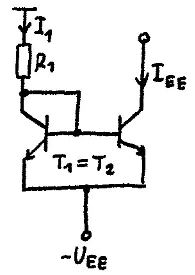


a)



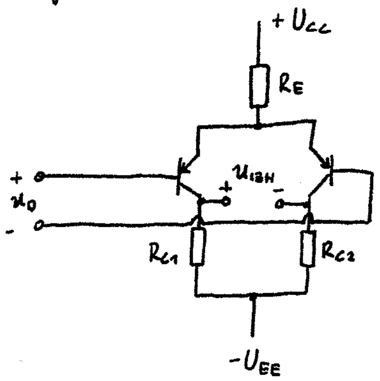
$$I_{EE} = \frac{U_z - U_{BE0}}{R_E}$$

b) tokovno zrcalo



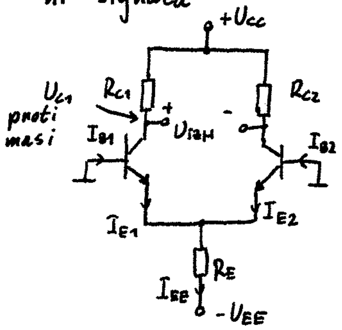
$$I_{EE} \doteq I_{R1} = \frac{U_{EE} - U_{BE0}}{R_1}$$

• Stopnja s PNP tranzistorji:



Analiza delovne točke:

- ni signala



$$I_{E1} = I_{E2} = \frac{I_{EE}}{2}$$

če na bazah isto krmiljenje

$$I_{c1} \doteq I_{E1} = \frac{I_{EE}}{2}$$

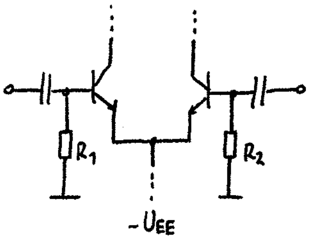
$$I_{c2} \doteq I_{E2} = \frac{I_{EE}}{2}$$

$$U_{izh} = U_{c1} - U_{c2} = (U_{cc} - I_{c1} R_{c1}) - (U_{cc} - I_{c2} R_{c2}) =$$

$$= \frac{I_{EE}}{2} (R_{c2} - R_{c1})$$

, $U_{izh} = 0$ če sta R_{c1} in R_{c2} enaka

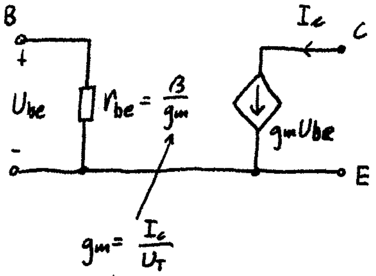
$$R_E = \frac{U_{RE}}{I_{EE}} = \frac{U_{EE} - U_{BE0}}{I_{EE}}$$



$R_1 = R_2$ za izločanje DC komponente!

Analiza vezja pri krmiljenju:

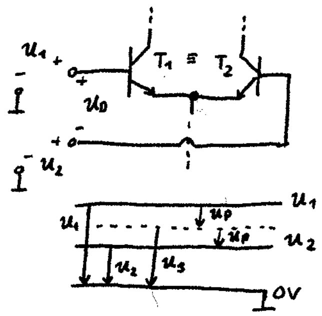
uporabimo linearni model za aktivno podnožje



Komponenti krmiljenja: $u_p \ (u_D)$

- protifazna (diferencialna) komponenta
- sofazna komponenta

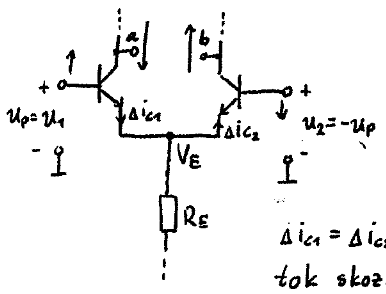
u_s



$$u_p = \frac{u_1 - u_2}{2} = \frac{u_D}{2}$$

$$u_s = \frac{u_1 + u_2}{2}$$

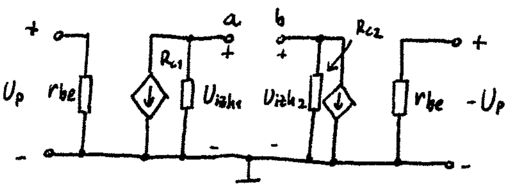
Analiza in model za protifazno komponento



$\Delta i_{c1} = \Delta i_{c2}$
tok skozi R_E se ne spreminja, tudi V_E konst.

za majhne signale masa

malosignalni model:



vhodna upornost za diferencialno napetost:

$$r_{vhD} = 2 \cdot r_{be}$$

$$U_{izh1} = -g_m \cdot U_{be1} \cdot R_c = -g_m R_{c1} \cdot U_p$$

$$U_{izh2} = -g_m U_{be2} \cdot R_c = -g_m R_{c2} \cdot (-U_p)$$

$$U_{izh} = -g_m R_{c1} U_p + g_m R_{c2} (-U_p) =$$

$$= -g_m (R_{c1} + R_{c2}) U_p$$

$$A_p = \frac{U_{izh}}{U_p} = \underline{-g_m (R_{c1} + R_{c2})} = -g_m \cdot 2 \cdot R_c = \underline{-2 g_m R_c}$$

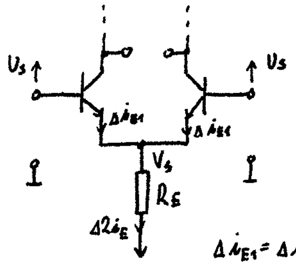
$$A_D = \frac{U_{izh}}{U_D} = \underline{-g_m R_c}$$

$$U_D = 2 \cdot U_p$$

14.3.2013

π!

Analiza in model za sofazno komponento

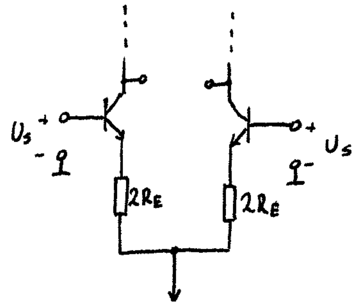


skupno dvigamo oba U_s vhoda, priklopljena na U_s

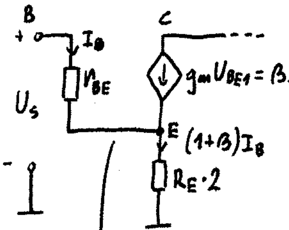
$\Delta i_{E1} = \Delta i_{E2} = \Delta i_E$

V_s ni več fiksna!

vezje razcepimo na dva!

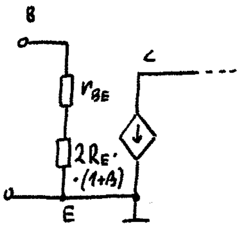


malosignalni model:



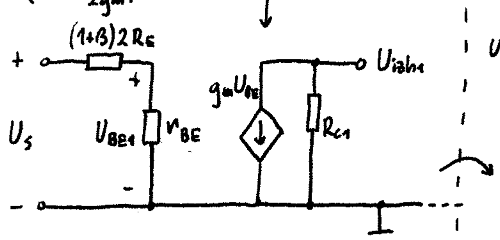
–||–

to sponko prestavimo tako, da ne spremenimo napetosti na r_{BE} → $2R_E$ v serijo z upornostjo $(1+\beta)\cdot 2R_E$



vhodna upornost je:

$$r_{VHS} = \frac{(1+\beta)2R_E + r_{BE}}{2} = \doteq \beta\left(R_E + \frac{1}{2g_m}\right)$$



enako na tej strani!

$$U_{BE1} = U_s \frac{r_{BE}}{r_{BE} + 2(1+\beta)R_E} = \quad \left(r_{BE} = \frac{\beta}{g_m}\right)$$

$$= U_s \frac{\frac{\cancel{\beta}}{g_m}}{\frac{\cancel{\beta}}{g_m} + 2(\cancel{1+\beta})R_E} = \quad \beta \approx 1+\beta$$

$$= \ldots$$

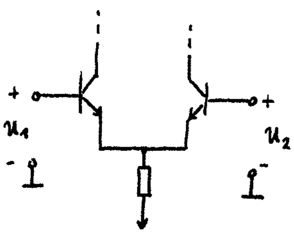
$$U_{izh1} = -g_m U_{BE} R_{c1} = -\frac{R_{c1}}{\frac{1}{g_m} + 2R_E} U_s$$

$$U_{izh2} = -\frac{R_{c2}}{\frac{1}{g_m} + 2R_E} U_s$$

$$U_{izh} = U_{izh1} - U_{izh2} = -\frac{R_{c1} - R_{c2}}{\frac{1}{g_m} + 2R_E} U_s$$

$$A_s = -\frac{R_{c1} - R_{c2}}{\frac{1}{g_m} + 2R_E}$$

Protifazno in sofazno vzbujanje



$$u_p = \frac{u_1 - u_2}{2}$$

$$u_s = \frac{u_1 + u_2}{2}$$

$$(u_p = u_1 - u_2)$$

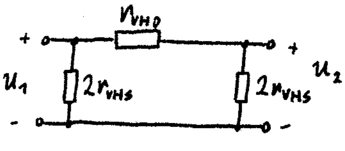
superpozicija:

$$U_{izh} = A_p U_p + A_s U_s$$

$$\downarrow$$

$$A_D = \frac{1}{2} A_p$$

vhodna upornost:



ponavadi:

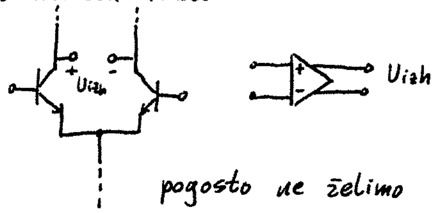
$r_{VHS} \gg r_{VHD}$

CMRR - Common Mode Rejection Ratio
(Rejekcijski faktor)

$$CMRR = \left| \frac{A_D}{A_S} \right|$$

$$CMRR_{dB} = 20 \cdot \log \left| \frac{A_D}{A_S} \right|$$

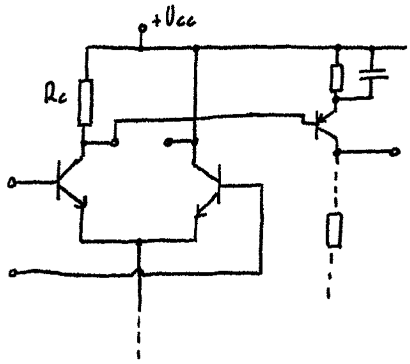
simetričen izhod:



pogosto ne želimo simetričnegu izhoda

Nesimetrični izhod

a) pri nekaterih izvedbah:



protifazno:

$R_{c1} = R_c$

$R_{c2} = 0$

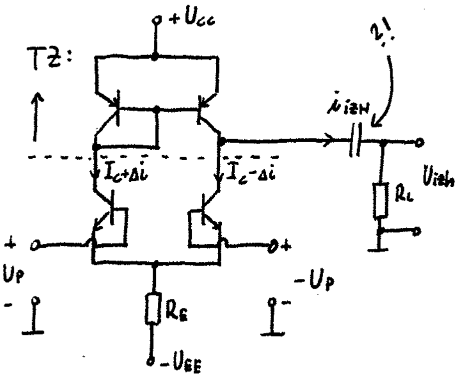
$A_D = -g_m R_c$

sofazno:

$$A_s = - \frac{R_{c1} - \cancel{R_{c2}}}{\frac{1}{g_m} + 2R_E}$$

rabimo velik $R_E \rightarrow$ tokovni vir!

b) aktivno breme

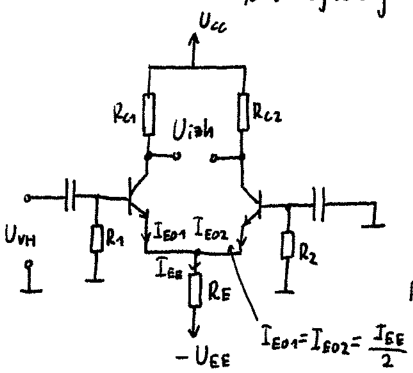


$i_{izh} = I_c + \Delta i - I_c + \Delta i = 2\Delta i$

$|\Delta i| = g_m U_{be} = g_m U_P$

protifazno krmiljenje: $U_{be1} = U_P$

Zgled določi delovno točko ter ojačanje $A = \frac{U_{izh}}{U_{vh}}$ za narisani ojačevalnik:



$U_{cc} = U_{EE} = 15\,V$

$U_{BE0} = 0.7\,V$

$T_1 \equiv T_2$

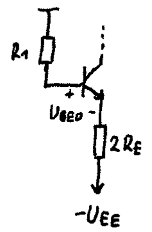
$\beta = 200$

$R_E = 5\,k\Omega$

$R_1 = R_2 = 100\,k\Omega$

$R_{c1} = R_{c2} = 2.5\,k\Omega$

R_E damo na enostran:



$I_{E0} \doteq I_{C0}$

$I_{E0} = (1+\beta) I_{B0}$

$$R_1 I_{B0} + U_{BE0} + 2R_E(1+\beta) I_{B0} - U_{EE} = 0$$

$$I_{B0} = \frac{U_{EE} - U_{BE0}}{R_1 + 2R_E(1+\beta)} = \frac{14.4V}{2.1\,M\Omega} =$$

$I_{B0} = 6.77\,\mu A$

$I_{C0} = 1.36\,mA$

AEV - P - 15

$u_1 = U_{VH}$
$u_2 = 0$

$U_P = \frac{u_1 - u_2}{2} = \frac{U_{VH}}{2}$

$U_S = \frac{u_1 + u_2}{2} = \frac{U_{VH}}{2}$

$U_{izh} = A_P U_P + A_S U_S$

$A_S = 0 \quad (T_1 = T_2,\ R_{c1} = R_{c2})$

$A = \frac{U_{izh}}{U_{VH}} = \frac{U_{izh}}{2U_P} = \frac{A_P}{2}$

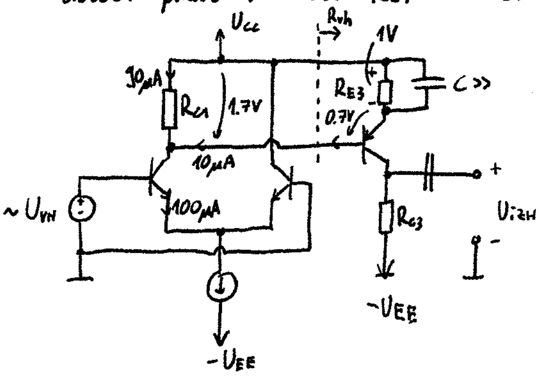
$\downarrow$

$A_P = -g_m (R_{c1} + R_{c2}) = -2 g_m R_c$

$\underline{A = -g_m R_c = -132}$

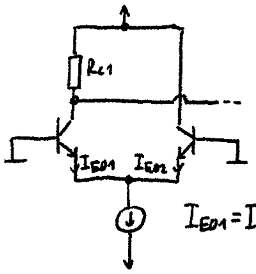
Zgled

določi pravo vrednost R_{c1} in skupno ojačanje $A = \frac{U_{izh}}{U_{VH}}$ narisanega vezja:



$U_{cc} = U_{EE} = 15V$
$|U_{BE0}| = 0.7V$
$I_{EE} = 200\mu A$
$\beta = 100$
$R_{c3} = 15\ k\Omega$
~~$R_{E3} = 1\ k\Omega$~~
$I_{E03} = 1mA$
$R_{E3} = 1k\Omega$

DC razmere:



$I_{E01} = I_{E02} = 100\mu A$

$U_{Rc1} = 1.7V$

$I_{Rc1} \doteq 100\mu A$

$R_{c1} = \frac{1.7V}{100\mu A} = 17k\Omega$ ← dodamo tok I_{B3}

$R_{c1} = \frac{1.7V}{100\mu A - \frac{I_{E3}}{\beta}} = \underline{\underline{18.89\ k\Omega}}$, $\frac{I_{E3}}{\beta} = 10\mu A$

izračunajmo R_{vh} za T3
$\sim \beta R_{E3} = 100\ k\Omega$
če upoštevamo R_{vh3}:
$R_{c1} = 20.5k\Omega$

AC razmere:

21.3.2013

pomlad!

$U_1 = U_{VH}$ $\quad U_P = \frac{U_1 - U_2}{2} = \frac{U_{VH}}{2}$

$U_2 = 0$ $\quad U_S = \frac{U_1 + U_2}{2} = \frac{U_{VH}}{2}$

$U_{izhdif} = A_P \cdot U_P + A_S \cdot U_S$

$A_u = A_{udif} + A_{BE}$

$A_S = -\frac{R_{c2} - R_{c1}}{\frac{1}{g_{m1,2}} + 2R_E} \doteq 0$, $R_E \to$ proti ∞

splošna $A_P = -g_m(R_{c1}^* + \cancel{R_{c2}}) = -g_m(R_{c1} \| R_{vh3}) = \underline{\underline{-8.79}}$, $R_{c1}^* \to R_{c1} \| R_{vh3}$

$g_m = \frac{I_{c1}}{U_T}$

samo $r_{\pi 3} = \frac{U_T}{I_{B3}} = \frac{\beta}{g_m} = \cancel{2.95}\ k\Omega$ $2.56\ k\Omega$

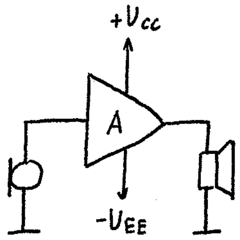
ojačanje za T3:

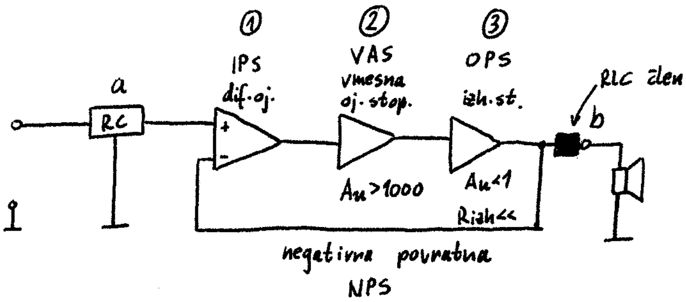
$A_{CE} = -g_{m3} R_{c3} =$
$= \underline{\underline{-584}}$

$A_{udif} = \frac{1}{2} A_P = \underline{\underline{-4.39}}$

$A_u = A_{CE} \cdot A_{udif} = \underline{\underline{2566}}$

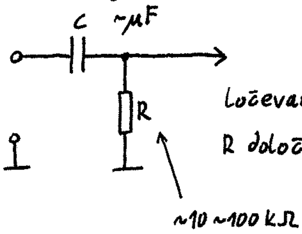
III. Močnostni ojačevalniki





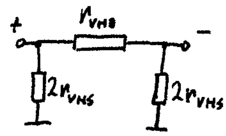
a) Vhodno RC vezje:

- preprosta vezava:

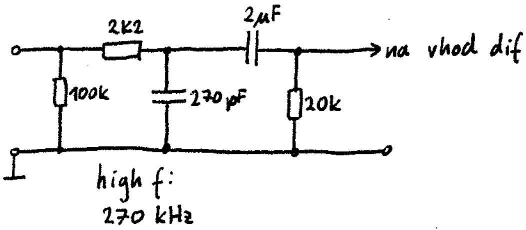


Ločevanje DC komponente, R določuje delovno točko

vhodna upornost dif. ojač:

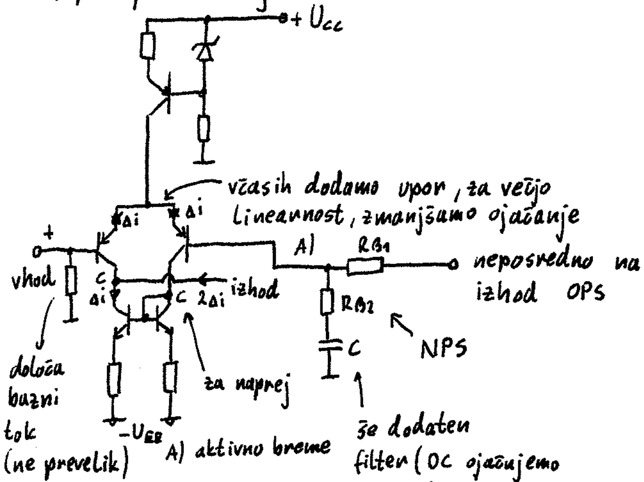


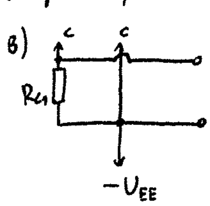
- VF filter:



① IPS

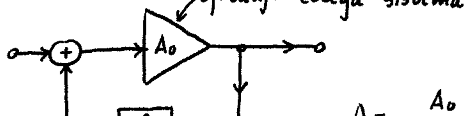
input power stage





R_{B1} določa delovno točko desnemu tranzistorju

NPS: DC razmere samo R_{B1}
AC razmere delilnik R_{B1}, R_{B2}



$$A = \frac{A_0}{1 + B A_0}$$

naš delilnik R_{B1}, R_{B2}, z minusom

za AC: $B_{AC} = -\frac{R_{B2}}{R_{B1} + R_{B2}} \longrightarrow A = \frac{-1}{B_{AC}} = 1 + \frac{R_{B1}}{R_{B2}}$

za DC: $B_{DC} = -1 \rightarrow A = 1$

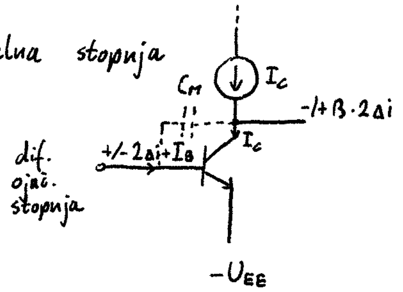
~~8~~

28.3.2013

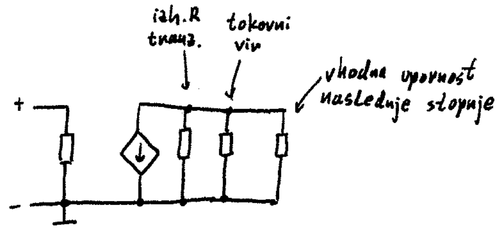
② VAS

Vmesna ojačevalna stopnja

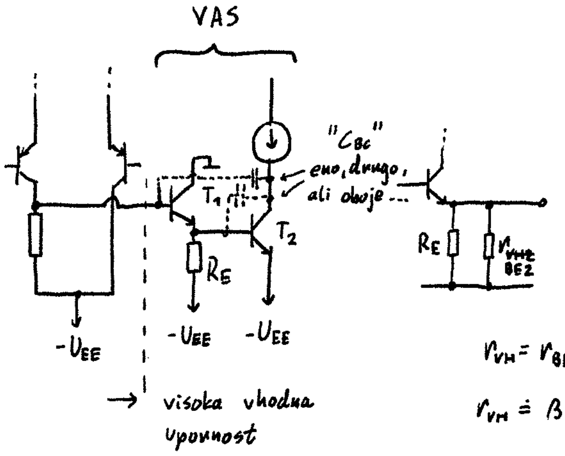
a) stopnja CE



$\Rightarrow$



b)

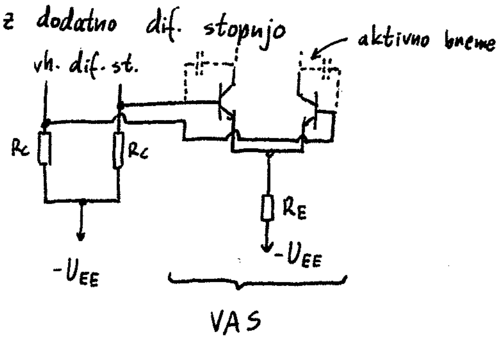


$r_{VH} = r_{BE} + (1+\beta)R_E \,||\, r_{BE2}$

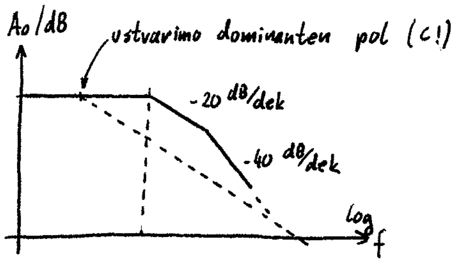
$r_{VH} \doteq \beta r_{be2}$ ← β-krat večje vhodna upornost v VAS

$r_{izH} = (R_E || r_{be2}) || \left(\frac{r_{izh\,dif.} + r_{be1}}{1+\beta} \right)$ ← nizka!

c) z dodatno dif. stopnjo



moramo paziti na stabilnost, visoke frekvence lahko nastanejo tudi zaradi popačenj znotraj vezja ... dodamo kondenzator proti masi (zmanjšamo ojačanje za visoke frekvence)



- ko imamo fazo pri $T = -\beta A_0$ 180°, želimo amplitudo pod 1 (0 dB)
- ko imamo amplitudo ojačanja $T = 1$, želimo manjšo fazo od 180° (recimo rezerva 45°)

povratna zanka zaradi stabilnosti ne sme biti prevelika (da bi preveč zmanjšali A_0)

AEV - P - 18

V praksi za zgornjo frekvenčno mejo ojačevalnika vzamemo 500 kHz.

- višje ne gremo zavadi stabilnosti (približamo se internim polom A_0)
- nižje ne gremo zavadi popačenja (v povratni zanki → čim večji T pri visokih f)

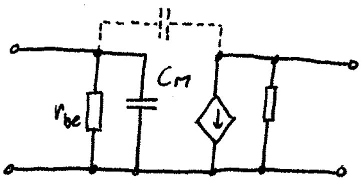
premik pola realiziramo s kondenzatorjem (ponavadi v VAS) "C_{BC}" oziroma C_M

Millerjeva transformacija:

$C_M = (1+|A|) \cdot C_{BC}$

mejna frekvenca:

$f_m = \frac{1}{2\pi C_M R_{eq}}$



$R_{eq} = r_{be} \| r_{izhdif}$

$\cancel{g_m}$

$A_u = -g_m R_C$ ← ne povsem, ker C_{BC} dodaja impedanco proti masi (U_{be} je majhna)

$A_u = -g_m \left[R_C \| \frac{1}{\omega C_M}\right]$ bolj natančno...

3 Izhodna ojačevalna stopnja

$R_L = 8\,\Omega$

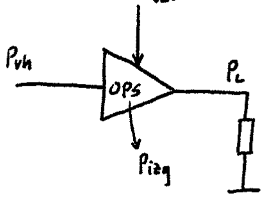
$P_L = 100\,W$ (rms)

↳ $I_{ef} = \sqrt{\frac{P_L}{R_L}} = 3.5\,A$

max 5A (za sinusni)

$U_{ef} = 28.3\,V$

max 40 V



$P_L \gg P_{vh}$

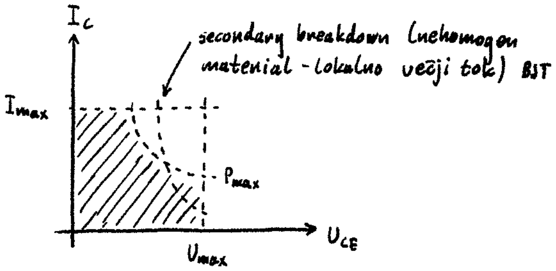
$\eta = \frac{P_L}{P_{bat}}$

P_{vh} zanemarljiva...

$\Gamma = \frac{P_{Lmax}}{P_{izgmax}}$ ob različnih trenutkih

Močnostni tranzistorji (BJT, MOSFET)

- maksimalni tok I_C
- maksimalna napetost U_{CE} (preboj)
- maksimalna moč P_{max} (P_{CE})



4.4.2013

Termične razmere

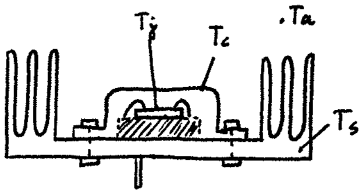
$P_{max} = P_{CE}$
(P_0)

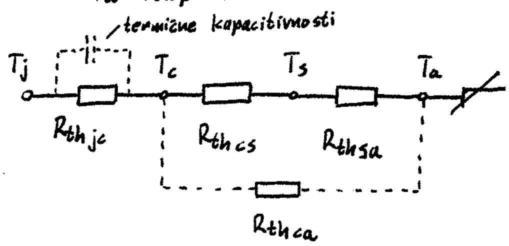
moč omejena z T_{jmax} = 150°C - 200°C

T_c - temp ohišja

T_s - temp hladilnega telesa

T_a - temp okolice



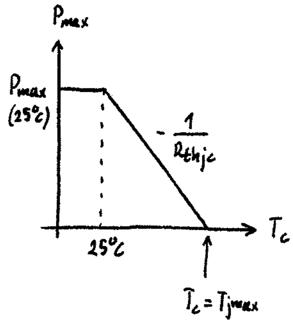


$R_{th}\left[\frac{°C}{W}\right] = \frac{1}{G_{th} \cdot A}$

$G_{th}\left[\frac{W}{°C\,cm^2}\right]$

$P_{CEmax} = \frac{T_j - T_a}{R_{thjc} + R_{thcs} + R_{thsa}}$

AEV - P - 19



power-derating curve

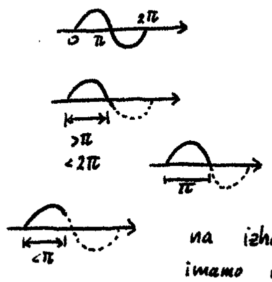
Razredi močnostnih ojačevalnih stopenj

A – teče signalni tok čez celo periodo (2π)

AB – signalni tok od π do 2π

B – signalni tok teče čez π periode

C – signalni tok teče čez manj kot π



na izhodu CE imamo nihajni LC krog, vsiljujemo samo ob trenutkih

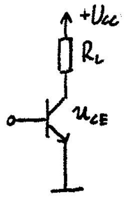
D – stikalni ojačevalniki

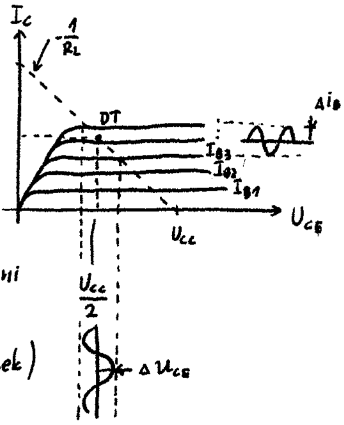
E – podobno

G – več napajanj - prilagajamo amplitudi vhodnega signala

H, S – ...

Razred A:





čez breme teče nek enosmerni delovni tok (kar nam sicer poslabša izkoristek)

$\Delta u_{CEmax} = \frac{U_{cc}}{2}$

$\Delta u_{CE} = k \cdot \frac{U_{cc}}{2}$ $\quad k = 0 \div 1$ faktor izkrmiljenja

$\eta = \frac{P_{L\sim}}{P_{BAT}}$ izmenična moč!

$i_c = I_c + I_c \sin \omega t$

$\Gamma = \frac{P_{Lmax\sim}}{P_{Tmax}}$ izgube na tranzistorjih (P_{Tmax})

$P_{bat} = U_{cc} \cdot \bar{i_c} = U_{cc} \cdot I_c =$

$= U_{cc} \cdot \frac{U_{cc}}{2R_L} = \underline{\underline{\frac{U_{cc}^2}{2R_L}}}$

$P_{L\sim} = \frac{\Delta u_{CE}^2}{R_L \cdot (\sqrt{2})^2} = \frac{\left(k \cdot \frac{U_{cc}}{2}\right)^2}{2 R_L} = \underline{\underline{\frac{k^2 U_{cc}^2}{8 R_L}}}$ (tudi Δu_L) $\quad 0 \div 25\,\%$ bat

$P_{Lmax} = \frac{U_{cc}^2}{8 R_L}$

$P_{Tmax} = P_{bat} - \cancel{P_{Lmax}} = P_{bat} - P_{L0c} - P_{L\sim}$

$\frac{U_{cc}}{2} \cdot \frac{U_{cc}}{2R_L} = \frac{U_{cc}^2}{4R_L}$ ← 50% bat ostalo na tranzistorju (25÷50%)

$\left[\begin{array}{l} P_{Tmax} = P_T \big|_{k=0} \\ P_{Lmax\sim} = P_{L\sim} \big|_{k=1} \end{array} \right.$

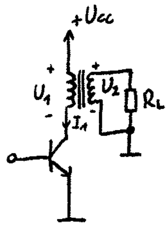
$\eta = \frac{P_{L\sim}}{P_{BAT}} = \frac{\frac{k^2 U_{cc}^2}{8 R_L}}{\frac{U_{cc}^2}{2R_L}} = \frac{k^2}{4}$ $\quad \underline{\underline{0\,\% \div 25\,\%}}$

$\Gamma = \frac{P_{Lmax\sim}}{P_{Tmax}} = \frac{P_{L\sim}(k=1)}{P_{Tmax}(k=0)} = \frac{1}{2}$ $\quad \underline{\underline{50\,\%}}$

$P_D = 50\ W$

$P_{Lmax\sim} = 25\ W$

Izvedba s transformatorjem:



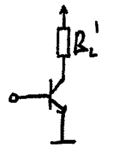
tako tudi impedančno prilagodimo breme na T

$U_2 = \frac{1}{n} U_1$ prestava

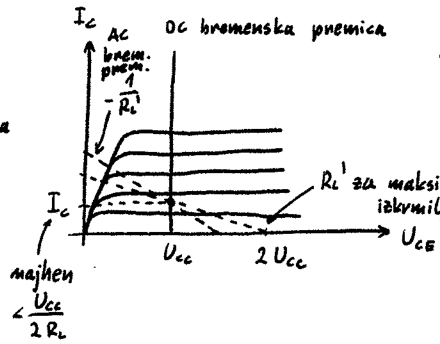
$I_2 = n I_1$

$\frac{U_2}{I_2} = \frac{1}{n^2} \frac{U_1}{I_1}$ (R_L)

$R_L' = n^2 \cdot R_L$ preslikana upornost



za izmenične signale



za maksimalen prenos moči n velik

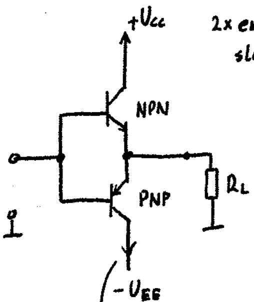
AEV - P - 20

pri izbiri n za maksimalno izkrmiljenje pri danem I_c:

$$\eta = \frac{k^2}{2} \quad \text{med } 0 \div 50\,\%$$

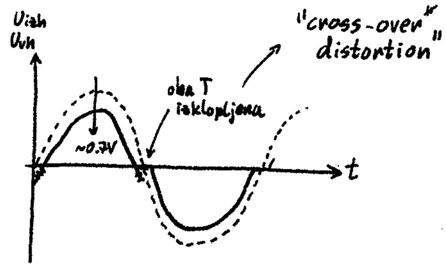
$$\Gamma = \frac{1}{2}$$

Razred B:



2x emitorski sledilnik

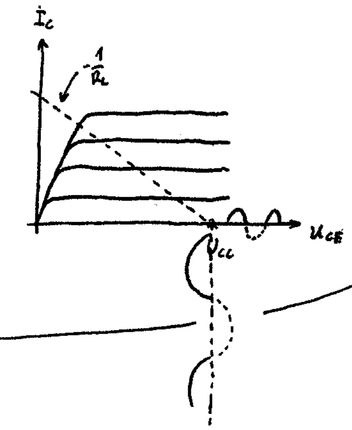
enosmerni tok ne teče



ojačanje:

$A_u \approx 1$

$A_i \approx \beta$



energijska bilanca:

$$\eta = \frac{P_{L\sim}}{P_{bat}}$$

$$\Gamma = \frac{P_{L\sim max}}{P_{T max}}$$

poenostavimo:

- gledamo čez pol-periode
- predvidevamo lep sinus

Izračun:

11.4.2013

$$P_{bat} = \frac{1}{\pi}\int_0^{\pi} U_{cc}\, i_c(\omega t)\, d\omega t = \frac{1}{\pi}\int_0^{\pi} U_{cc} \overbrace{\frac{k \cdot U_{cc}}{R_L}}^{I_c} \sin \omega t \; d\omega t = \frac{1}{\pi}\, \frac{k \cdot U_{cc}^2}{R_L} \left(-\cos \omega t\right)\Big|_0^{\pi} =$$

$$= \frac{2}{\pi} \cdot \frac{k \cdot U_{cc}^2}{R_L}$$

$$\underset{\uparrow\, U_{eff},\, I_{eff}}{P_{L\sim}} = \frac{k \cdot U_{cc}}{\sqrt{2}} \cdot \frac{I_{RL}}{\sqrt{2}} = \overbrace{\frac{k \cdot U_{cc}}{\sqrt{2}}}^{U} \cdot \overbrace{\frac{k \cdot U_{cc}}{R_L \cdot \sqrt{2}}}^{I} = \frac{k^2 U_{cc}^2}{2 R_L}$$

$$\eta = \frac{P_{L\sim}}{P_{bat}} = \underline{\underline{\frac{k \cdot \pi}{4}}} \qquad \eta = 0 \div 78\,\% \qquad \text{mnogo boljе!}$$

$$P_T = P_{T1} + P_{T2} = P_{bat} - \overset{\doteq P_{L\sim} \text{ (DC komponente ni !)}}{P_L} =$$

$$= \frac{2}{\pi}\frac{k \cdot U_{cc}^2}{R_L} - k^2 \frac{U_{cc}^2}{2 R_L} = \frac{k\, U_{cc}^2}{R_L}\left(\frac{2}{\pi} - \frac{k}{2}\right)$$

da določimo P_{Tmax} moramo najti k, da je maks izgub:

$$\frac{\partial P_T}{\partial k} = 0$$

$$\frac{U_{cc}^2}{R_L}\left(\frac{2}{\pi} - \frac{k}{2}\right) + \frac{k\, U_{cc}^2}{R_L}\cancel{\left(\frac{2}{\pi} - \frac{1}{2}\right)} = 0$$

$$\cancel{2\pi} \quad \frac{2}{\pi} - \frac{k}{2} - \frac{k}{2} = 0 \quad \rightarrow k = \frac{2}{\pi}$$

$$k \doteq 0.6386$$

$$P_{Tmaks} = \frac{2}{\pi^2} \cdot \frac{U_{cc}}{R_L} = \frac{U_{cc}}{R_L} \cdot 0.203$$

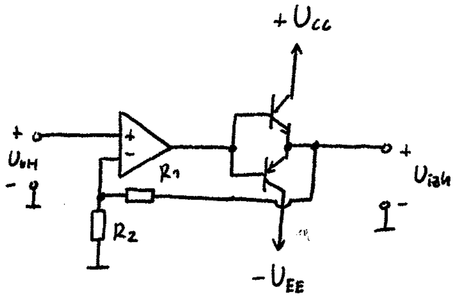
$$\Gamma = \frac{\overset{k=1}{P_{L\sim max}}}{\underset{k=\frac{2}{\pi}}{P_{T max}}} = \frac{\pi^2}{4} \doteq \underline{\underline{2.5}}$$

$$P_{T1max} + P_{T2max} = \frac{P_{Tmax}}{2}$$

npr. $P_{T1max} = 1\,W \implies P_{Lmax} = 5\,W$

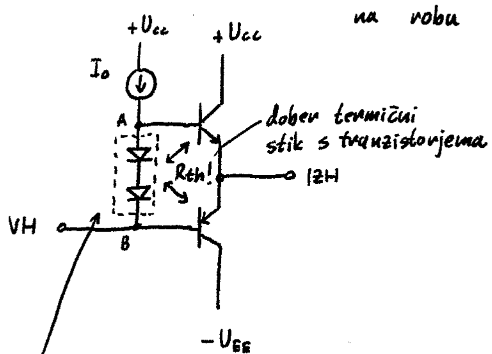
AEV - P - 21

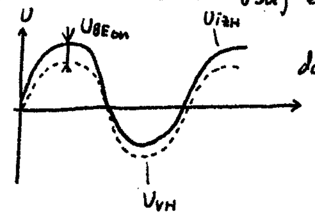
stopnja kot izhod OP-AMPa



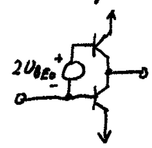
Razred AB:

med bazami dodamo neko napetost ($\sim 2 \cdot U_{BEo}$) sta oba tranzistorja na robu prevajanja (ob vsakem času vsaj eden aktiven!)





dodamo nekaj DC komponente



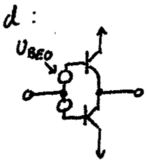
to vmesno napetost pogosto nastavimo tako, da teče nek majhen DC tok (izničimo popačenje ob prehodu čez ničlo)

I_o poskrbi za pravo napetost na diodah in delovno točko prejšnje stopnje!

Zagotavljati mora tudi dovolj toka za bazo zgornjega tranzistorja

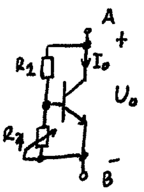
Diodi tud izboljšata temp stabilnost! (diodi proti BE spoju)

če pa vhodni signal napeljemo na sredino, izboljšamo izhod:



energijska bilanca (močnostna) je enaka kot pri razredu B

nastavljanje U_o!



$I_o = I_c = \beta I_B$

$I_E = (\beta+1) I_B$

$U_o = U_o(R_1)$?

- $I_{R1} = \frac{U_{BEo}}{R_1}$
- $I_{R2} = I_{R1} + I_B$
- $I_o = I_{R2} + \beta I_B = \beta I_B + I_B + \frac{U_{BEo}}{R_1}$

$I_o = (\beta+1) I_B + \frac{U_{BEo}}{R_1}$

$I_B = \frac{I_o - \frac{U_{BEo}}{R_1}}{\beta+1}$

$U_{CE} = U_o = R_2 I_{R2} + U_{BEo} =$

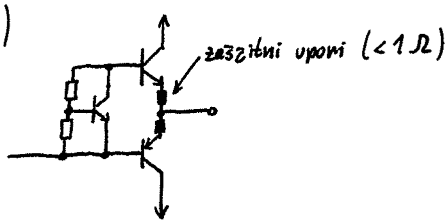
$U_o = (I_B + I_{R1}) R_2 + U_{BEo} = \left[\frac{I_o - \frac{U_{BEo}}{R_1}}{\beta+1} + \frac{U_{BEo}}{R_1}\right] \cdot R_2 + U_{BEo}$

če β velik

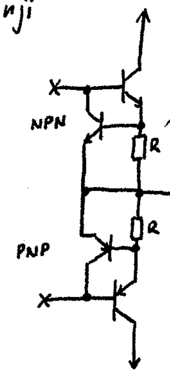
$U_o = U_{BEo}\left(1 + \frac{R_2}{R_1}\right)$

Zaščita pred prevelikim tokom:

a)



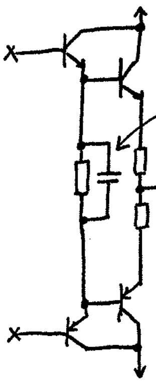
b) s tranzistorji



ob vklopu ta tranzistor manjša tok skozi močnostnega

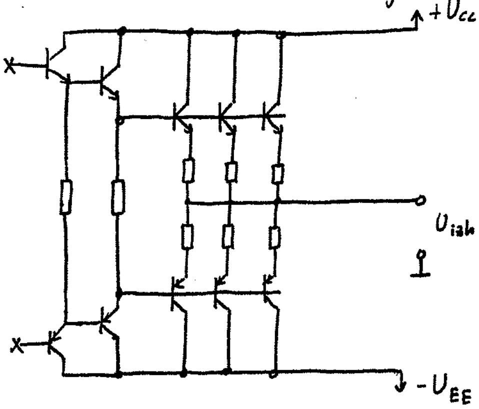
$I_{max} \approx \frac{0.7V}{R}$

včasih rabimo neko pred-izhodno stopnjo, da dobimo dovolj toka za baze izhodnih tranzistorjev

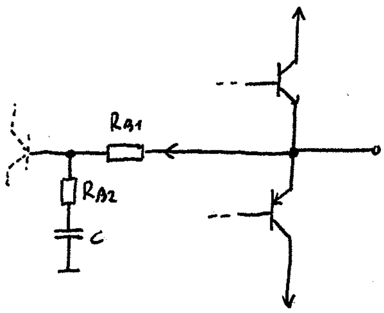


pohitri preklope, ko gre T iz prevodne v zaporno delovanje mu ostane nekaj naboja, ta lahko steče skozi R||C in se hitreje sprazne

primer z več izhodnimi tranzistorji:

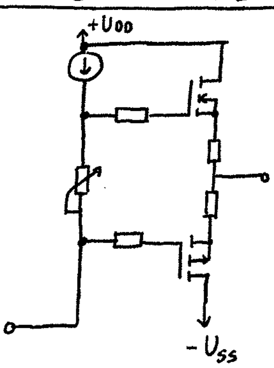


Negativna povratna vezava, NPS



povratna zanka skrbi tudi za stabilnost vmesne stopnje (ta nima emitorskega upora)

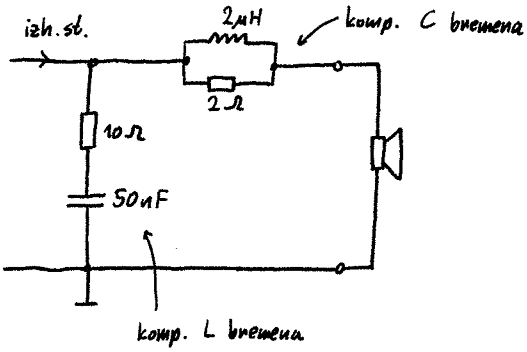
Izvedbe z MOSFETi:



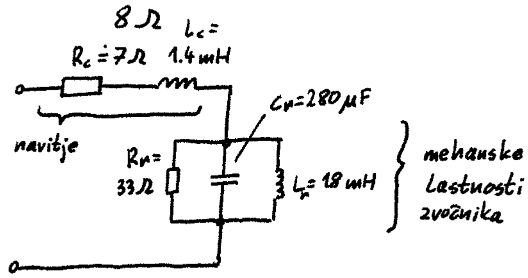
AEV - P - 23

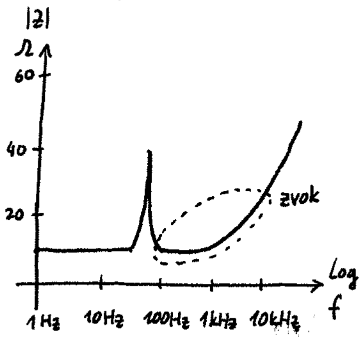
Na izhodu želimo kakršno-koli breme videti kot upor (zaradi namenov stabilnosti), uporabimo:

Zobel-ovo vezje



nadomestni model zvočnika:





določi površino hladilnega telesa za 100 W ojač. v AB vezavi z izbranima izhodnima tranzistorjema (NPN+PNP)

$P_{T1max} = P_{T2max} = 75\,W \quad (T_c = 25°C)$

$T_{jmax} = 150\,°C$

$R_{th\,cs_{1T}} = 1\,°C/W$

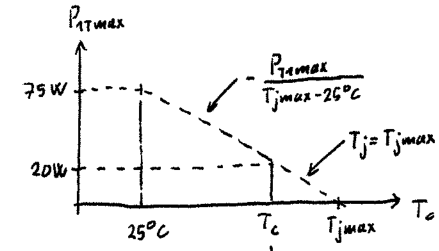
$\sigma_{th\,sA} = 2.5 \cdot 10^{-3}\,\frac{W}{°C\,cm^2}$

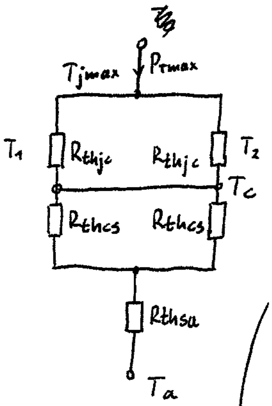
$T_a = 50°C$

faktor $\Gamma = \frac{P_{Lmax\sim}}{P_{Tmax}} = \frac{P_{L\sim}(k=1)}{P_{Tmax}(k=\frac{2}{\pi})} \doteq 2.5$ ← predavanja — AB ali B razred

$P_{Tmax} = \frac{P_{Lmax\sim}}{\Gamma} = 40\,W$ (na obeh)

$P_{1Tmax} = 20\,W$





$$T_c = 25°C - \frac{T_{jmax}-25°C}{P_{Tmax}(25°C) - \phi} \cdot \left(P_{1Tmax}(25°C) - P_{1T}\right)$$

(ΔT / ΔP, ΔP_{1T}; ~~150~~ ~~75°~~)

$\underline{T_c = 116.6°C}$

$R_{thsa} = \frac{1}{\sigma_{thsa} \cdot A_s}$

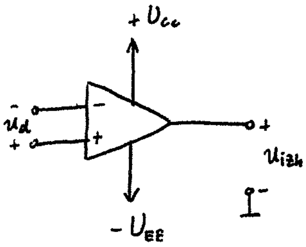
$P_{Tmax} = \frac{T_c - T_a}{(R_{thcs1T} + \cancel{R_{thjc1T}})/2 + R_{thsa}}$

$R_{thsa} = 1.165\,°C/W$

$\underline{\underline{A_s = 343.3\,cm^2}}$

4. Operacijski ojačevalniki

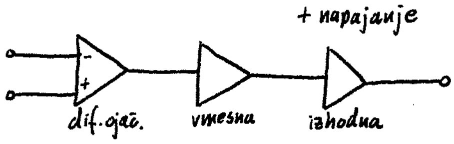
(OP-AMP)



$u_{izh} = A_o \cdot u_d$ idealno $A_o \to \infty$

realno $A_o = 10^4 \div 10^6$

Blokovna shema:



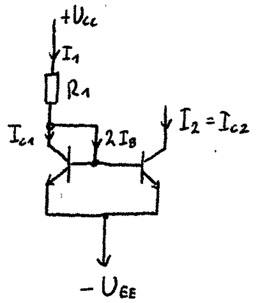
dodatni gradniki:

- tokovni viri (za DT)
- premikalnik nivoja (level-shifter) $u_d = 0 \to u_{izh} = 0$
- zaščitna vezja ($i_{izh\,max}$)

AEV - P - 25

Tokovna zrcala - posebnosti

1) Navadno

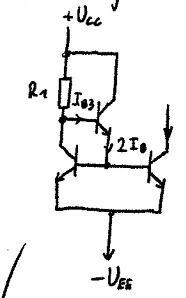


$$I_1 \doteq I_2 \doteq \frac{U_{cc}-U_{BE}+U_{EE}}{R_1}$$

$$I_1 = I_{c1} + 2I_B = I_{c1} + \overbrace{\underline{\underline{\frac{2I_{c1}}{\beta_1}}}}^{\Delta I} = I_{c1}\left(1+\frac{2}{\beta}\right)$$

$$I_2 = \frac{I_1}{1+\frac{2}{\beta}}$$

2) Izboljšano

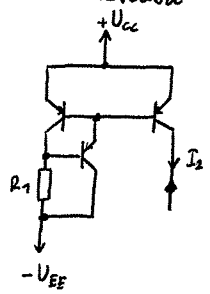


$$I_{B3} = \frac{2I_B}{\beta_3}$$

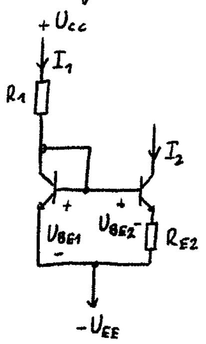
$$\Delta I = \frac{2I_B}{\beta_3} = \underline{\underline{\frac{2\cdot I_{c1}}{\beta_3\beta_1}}}$$

$$I_1 \doteq \frac{U_{cc}-U_{BE1,2}-U_{BE3}+U_{EE}}{R_1}$$

PNP izvedba:



3) Widlarjev tokovni vir



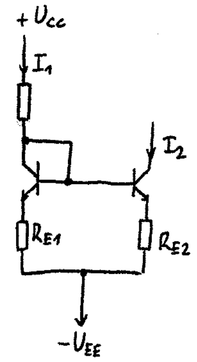
zanemarimo I_B!

$$U_{BE2} = U_{BE1} - I_2 R_{E2}$$

$$\frac{I_1}{I_2} = \frac{e^{\frac{U_{BE1}}{U_T}}}{e^{\frac{U_{BE2}}{U_T}}} = e^{\frac{U_{BE1}-U_{BE2}}{U_T}} = e^{\frac{I_2 R_{E2}}{U_T}}$$

$$\ln\frac{I_1}{I_2} = \frac{I_2 R_{E2}}{U_T} \longrightarrow I_2 = \frac{U_T}{R_{E2}} \ln\frac{I_1}{I_2}$$

4) Uporaba dveh R_E



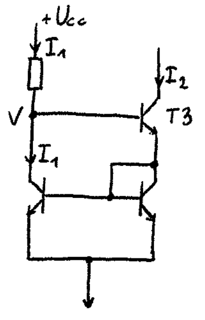
$$U_{BE2} = U_{BE1} + I_1 R_{E1} - I_2 R_{E2}$$

$$\vdots$$

$$\ln\frac{I_1}{I_2} = \frac{-I_1 R_{E1} + I_2 R_{E2}}{U_T} \longrightarrow I_2 = I_1 R_{E1} + \frac{U_T}{R_{E2}} \cdot \ln\frac{I_1}{I_2}$$

še vedno imamo vpliv earlyjeve napetosti
če spreminjamo U_{CE} se spreminja I_c!

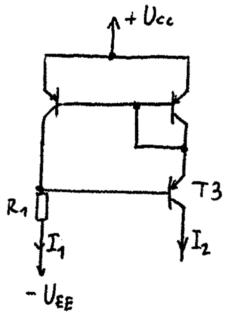
5) Wilsonovo tokovno zrcalo



-negativna povratna vezava

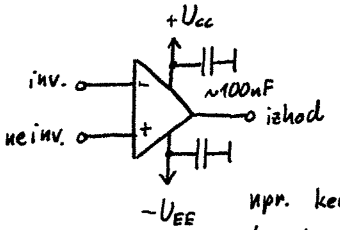
če se I_2 poveča, se poveča tudi I_1, zato se zmanjša potencial V, zato T3 nekoliko zapre (U_{BE3} se zmanjša)

PNP izvedba:



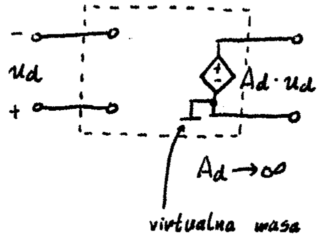
25.4.2013

Modeli in parametri operacijskih ojačevalnikov



npr. keramika
(uizek R_s)

1. Model idealiziranega OP-AMPa

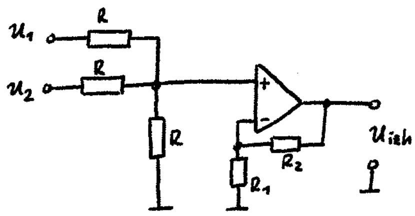


- oblika signala sledi vhodu (tudi pri visokih frekvencah)
- neodvisnost od napajanja in T
- velikost izhodnega signala ni omejena

Dve zlati pravili:

- v vhodni sponki ne teče nič toka
- negativna povratna vezava → $u_d \to 0$

■ Primer:



$$U_- = \frac{R_1}{R_1+R_2} u_{izh}$$

superpozicija!

$$u_2 = 0 \to U_+ = \frac{1}{3} u_1$$

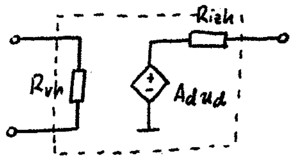
$$u_1 = 0 \to U_+ = \frac{1}{3} u_2$$

$$\to U_+ = \frac{1}{3}(u_1+u_2)$$

$$\frac{1}{3}(u_1+u_2) = \frac{R_1}{R_1+R_2} u_{izh}$$

$$u_{izh} = \frac{1}{3}\left(\frac{R_1+R_2}{R_1}\right)(u_1+u_2)$$

2. Delno realni model OP-AMPa

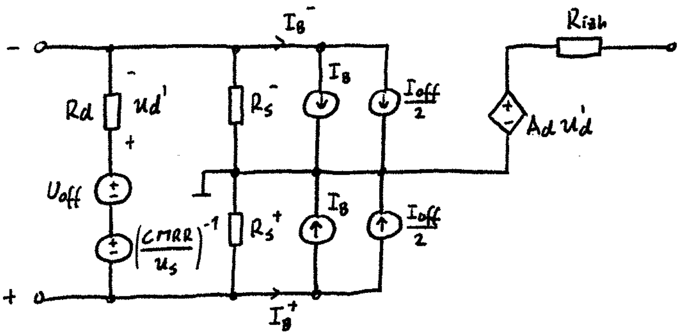


$R_{vh} = r_{vhd}$ ($100 k\Omega \div \sim T\Omega$)

$A_d \sim 10^4 \div 10^6$

$R_{izh} \sim$ nekaj $10\ \Omega$

3. Realni model OP-AMPa



$\frac{u_s}{CMRR}$ u_s sofazna komponenta

$CMRR = \left|\frac{A_d}{A_s}\right|$

$A_d \simeq 10 \div 1000 \frac{V}{mV}$

$R_d = r_{vhd}$ za bipol. $R_D = 2 r_{BE}$
za MOS $\sim T\Omega$

R_s^-, R_s^+ upornost za sofazne nap.
$R_s^+ \doteq R_s^- \doteq r_{be} + 2(\beta+1)R_E$ $\sim G\Omega, T\Omega$

U_{off} vhodna ničelna napetost $\sim \pm$ nekaj mV

$\alpha = \frac{dU_{off}}{dT}$ nekaj $\frac{\mu V}{°C}$

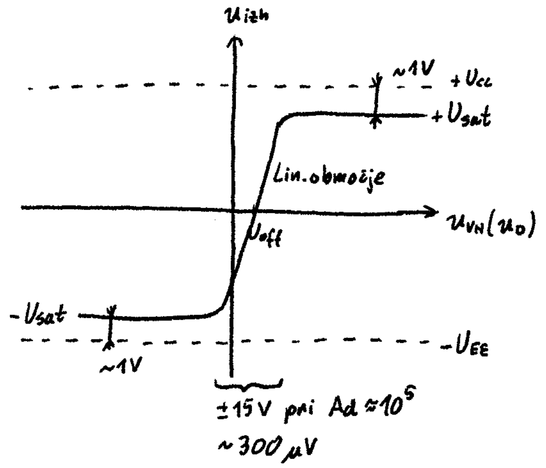
I_B^+, I_B^- tokova v vhodne sponke (notranja!)
sofazna komponenta I_B (input bias)
protifazna komp. I_{off} (input offset I)

$$I_B = \frac{I_B^+ + I_B^-}{2} \qquad I_{off} = I_B^- - I_B^+$$

bipol $\sim 20, 80\ nA$
unipol $< pA$

model še vedno za linearno območje
ni omejitve zaradi napajanja
ne upošteva sprememb napajalne napetosti
-ll- šumnih napetosti

Statična prenosna karakteristika OP-AMP:



pri "rail-to-rail" izvedbah je $U_{cc} - U_{sat}$ do 0.2 V

- Vpliv sprememb napajalnih napetosti

PSRR
↑
power supply rej. ratio

$$PSRR = \left| \frac{\Delta U_{supp.}}{\Delta u_D} \right| \qquad \Delta U_{supp.} = |\Delta U_{cc}| + |\Delta U_{EE}|$$

~10^5

~80-120 dB

pogosto v decibelih

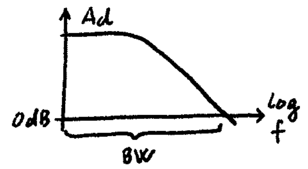
PRIMER:

PSRR = 110 dB

$\Delta U_{supp} = 0.3$ V

↳ $\Delta u_D = 1\,\mu V$

- Pasovna širina
  (bandwidth) BW



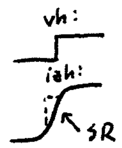
pogosto se podaja zmnožek ojačanja in pasovne širine

$$GBW = A_d\Big|_{BW} \cdot BW$$

G – gain

- Maksimalni gradient izh. napetosti
  (slew-rate) SR

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



- Čas vzpona
  (rise-time) čas med izhodom od 10 do 90% pri stopnici na vhodu

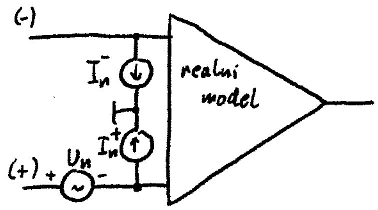
Šum pri OP-AMP

- specifična gostota šuma: $u_n \; \frac{V}{\sqrt{Hz}}$ $\quad i_n \; \frac{A}{\sqrt{Hz}}$
- integralni šum U_n V
  I_n A

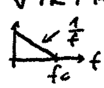
$$U_n = \sqrt{\int_{f_1}^{f_2} u_n^2 \, df}$$

$$I_n = \sqrt{\int_{f_1}^{f_2} i_n^2 \, df}$$

približna vrednost: $U_{npp} \doteq 5 \cdot U_n$



- termični šum (beli šum) $U_N = \sqrt{4kTR\Delta f}$ $\quad U_N = u_n\sqrt{f_2 - f_1}$
- 1/f šum $U_N = u_n \sqrt{f_c \ln \frac{f_2}{f_1}}$



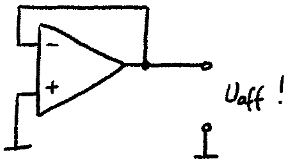
- shot noise
  tam, kjer nosilci premagujejo potencialno barievo
- burst noise
  nosilci se naključno ujemajo

AEV- P - 28

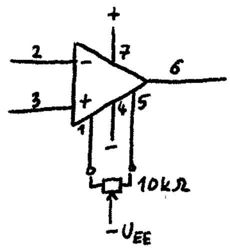
U_{off}, I_B, I_{off}

↓

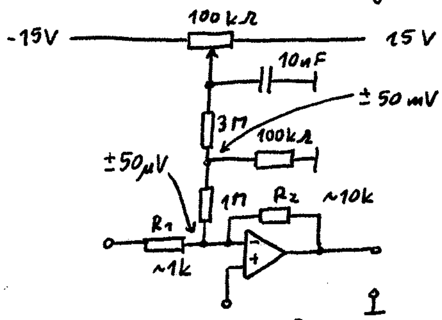
izvedbe z bipolarni tranzistorji imajo precej manjše napetosti
je tudi temperaturno odvisna!



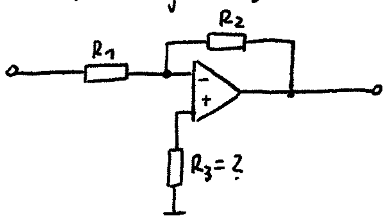
741 ima že dve dodatni sponki za kompenzacijo:



Vezje za zunanjo kompenzacijo:



Kompenzacija I_B:

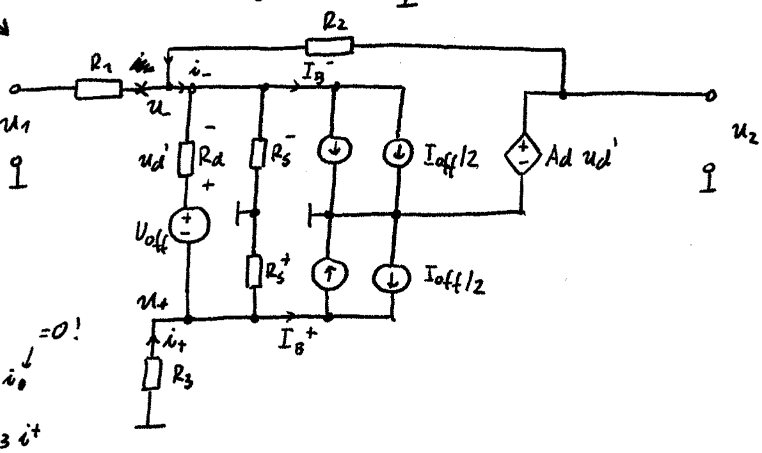


realni model
poenostavitve

$A_0 (A_d) \to \infty$

$R_{izh} \to 0$

$CMRR \to \infty$



$$\frac{u_2 - u_-}{R_2} - \frac{u_-}{R_1} - i_- = 0$$

$$u_2 = u_- + \frac{u_- R_2}{R_1} + i_- R_2 =$$

$$= u_-\left(1 + \frac{R_2}{R_1}\right) + i_- R_2 \quad ; \quad i_- = \frac{u_-}{R_s^-} + I_B^- - \underset{=0!}{i_0}$$

$$u_2 = u^-\left(1 + \frac{R_2}{R_1} + \frac{R_2}{R_s^-}\right) + R_2 I_B^- \quad ; \quad u^- = U_{off} - R_3 i^+$$

$$i^+ = I_B^+ + \frac{u^- - U_{off}}{R_s^+} + 0$$

$$u_2 = U_{off}\left(1 + \frac{R_2}{R_1}\right) + U_{off}\frac{R_2}{R_s} + R_2 I_B^- - \left(1 + \frac{R_2}{R_1} + \frac{R_2}{R_s^-}\right)$$

$$u_2 = \frac{R_2}{R_1 \| R_2 \| R_s^-} U_{off} + R_2 I_B^- - \frac{R_3 \| R_s^+}{R_1 \| R_2 \| R_s^-} R_2 I_B^+$$

↓

če tole spravimo na 0, se I_B odštejeta (oziroma točno toliko, da se odštejeta)

$$\underbrace{R_3 \| R_s^+}_{\text{DC upornost, ki jo vidi + sponka}} = \overbrace{R_1 \| R_2 \| R_s^-}^{\text{DC upornost, ki jo vidi - sponka}}$$

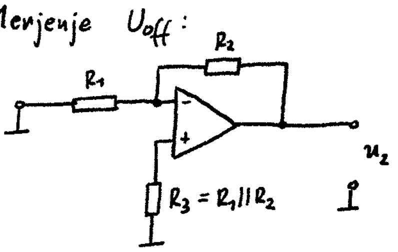
$$u_2 = \frac{R_2}{R_1 \| R_2 \| R_s^-} U_{off} + R_2 \underset{\uparrow \; I_B + \frac{I_{off}}{2}}{I_B^-} - R_2 \underset{\uparrow \; I_B - \frac{I_{off}}{2}}{I_B^+}$$

$$u_2 = \frac{R_2}{R_1 \| R_2 \| R_s} U_{off} + R_2 I_{off}$$

če $R_s^+ \doteq R_s^- \Rightarrow \underline{\underline{R_3 = R_1 \| R_2}}$

AEV - P - 29

Merjenje U_{off}:



$A_d \to \infty$

$CMRR \to 0$

$R_{izh} \to 0$

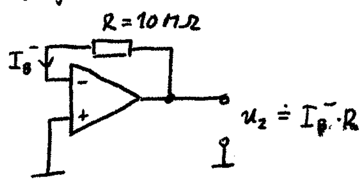
$R_s^+ = R_s^-$

$$\Rightarrow U_{off} = \frac{R_1 || R_2 || R_s^-}{R_2} \left(u_2 - R_2 I_{off} \right)$$

približno

$$U_{off} = \frac{R_1 || R_2}{R_2} u_2 = \frac{R_1}{R_1 + R_2} u_2$$

Merjenje I_B^-:

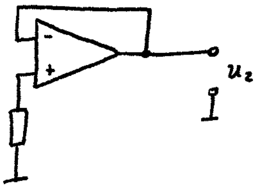


$$u_2 \doteq I_B^- \cdot R$$

namesto upora je lahko kondenzator

$$I_B^- = C \frac{\Delta U}{\Delta t}$$

$$I_B^- = \frac{u_2}{R} - \underbrace{U_{off} \left(1 + \frac{R}{R_s^-} \right)}_{napaka}$$



tale OP-AMP je pa malo bolj raztegujen

Zgled

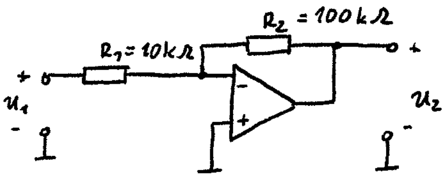
Za narisani ojačevalnik določi napetostno ojačanje A_B, vh. upornost in izh. upornost

parametri:

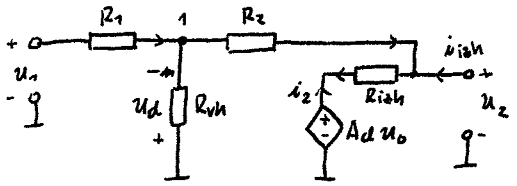
$R_{vh} (R_d) = 100\ k\Omega$ zanemarimo $U_{off}, I_B^+, I_B^-, R_s^+, R_s^-, \ldots$

$R_{izh} = 75\ \Omega$

$A_0 = 10^4$



delno realni model



$$u_2 = A_d u_d - R_{izh} i_2 = A_d u_d - R_{izh} \frac{A_d u_0 + (u_0)}{R_2 + R_{izh}}$$

$$u_2 = A_d u_d \left(1 - R_{izh} \frac{1 + \frac{1}{A_d}}{R_2 + R_{izh}} \right)$$

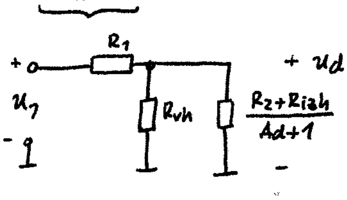
u_d:

$$1: \quad \frac{u_1 + u_d}{R_1} + \frac{u_d}{R_{vh}} + \frac{A_d u_d + u_d}{R_2 + R_{izh}} = 0$$

$$u_d \left(\frac{1}{R_1} + \frac{1}{R_{vh}} + \frac{A_d + 1}{R_2 + R_{izh}} \right) = - \frac{u_1}{R_1} \Rightarrow u_d = \frac{-u_1}{1 + \frac{R_1}{R_{vh}} + \frac{R_1 (A_d + 1)}{R_2 + R_{izh}}}$$

$$u_d = \frac{\underbrace{R_{vh} || \frac{R_2 + R_{izh}}{A_d + 1}}}{R_1 + R_{vh} || \frac{R_2 + R_{izh}}{A_d + 1}} \cdot (-u_1)$$

$$u_d = - u_1 \frac{1}{1 + R_1 \underbrace{\left(\frac{1}{R_{vh}} + \frac{1}{\frac{R_2 + R_{izh}}{A_d + 1}} \right)}_{\frac{1}{R_{vh} || \frac{R_2 + R_{izh}}{A_d + 1}}}}$$



končni rezultat:

$$A_B = - A_d \frac{1 - R_{izh} \frac{1 + \frac{1}{A_d}}{R_2 + R_{izh}}}{1 + \frac{R_1}{R_{vh}} + \frac{R_1 (1 + A_d)}{R_2 + R_{izh}}}$$

$$A_B \doteq - 9.974 \ldots$$

vhodna upornost:

idealno R_1, realno pride $R_{vhB} = R_1 + R_{vh} || \frac{R_2 + R_{izh}}{1 + A_d} \doteq 10.010\ k\Omega$

16.5.2013

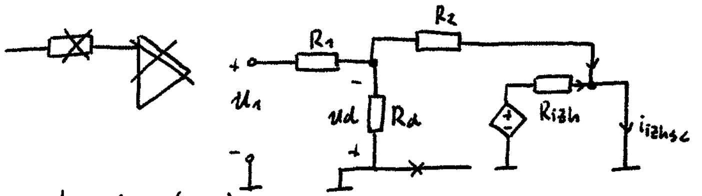
$R_{izh\beta} = \frac{u_2}{i_{izh}}$

↑
celotni sistem

po theveninu $R_{izh\beta} = \frac{U_{2oc}}{i_{izhsc}}$ → $U_{2oc} = -\frac{R_2}{R_1} \cdot u_1$ (R_{izh} nima vpliva pri $A_0 \to \infty$)

→ $i_{izhsc} = \frac{A_d u_d}{R_{izh}} + \frac{-u_d}{R_2} = u_d\left(\frac{A_d}{R_{izh}} - \cancel{\frac{1}{R_2}}\right)$ ker majhno

$= u_d \frac{A_d}{R_{izh}} = \dots$



za izvod u_d nezemo, da je R_d zelo velik

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

skupaj potem:

$$R_{izh\beta} = \frac{-\cancel{u_1} \frac{R_2}{R_1}}{-\cancel{u_1} \frac{\cancel{R_2}}{R_1+R_2} \frac{A_d}{R_{izh}}} = \frac{R_{izh}}{A_d} \cdot \underbrace{\frac{R_1+R_2}{R_1}}_{1+\frac{R_2}{R_1}} \doteq \frac{|A_\beta|}{A_d} R_{izh}$$

$1+\frac{R_2}{R_1}$ pogosto je to enako $\frac{R_2}{R_1}$

$\approx |A_\beta|$

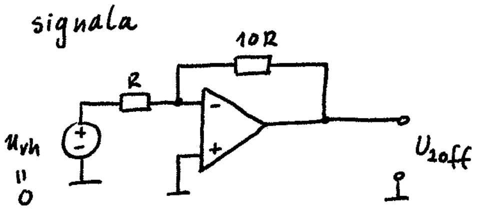
za neinvertirajočega:

$R_{vh\beta} \doteq \frac{A_d}{A_\beta} R_d$

$R_{izh\beta} \doteq \frac{A_\beta}{A_d} R_{izh}$

Zgled

Za narisani ojačevalnik določi maksimalno izhodno napetost, če na vhodu ni signala



$R = 15\ k\Omega$

$U_{off} = \pm 1\,mV$

$I_B = 200\ nA$

$I_{off} = \pm 50\ nA$

$CMRR \to \infty$

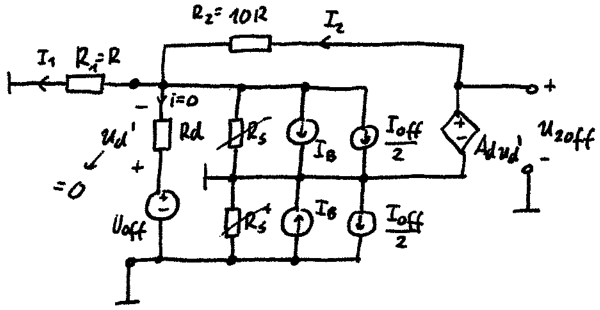
$R_d = 100\ k\Omega$

a) $A_0 = A_d \to \infty$

$R_s^- = R_s^+ \to \infty$

b) $A_0 = 10^4$

$R_s^- = R_s^+ = 10\ M\Omega$



$U_{2off} = R_2 i_2 + U_{off}$

$i_2 = \frac{U_{off}}{R_1} + I_B + \frac{I_{off}}{2}$

$U_{2off} = 10\ U_{off} + 10\ R I_B + 5\ R\ I_{off} + U_{off} =$

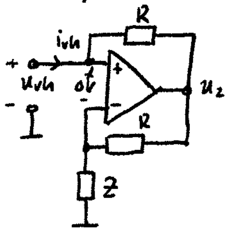
$= 11\ U_{off} + \underbrace{10\ R I_B}_{+} + 5\ R\ I_{off} =$

↑ ⊕1 mV ↑ ⊕50 nA

$U_{2off} = 11\ mV + 3.75\ mV + 30\ mV = \underline{44.75\ mV}$

Uporabna vezja z OP-AMP:

- tralalal ...
- negativni impedančni pretvornik



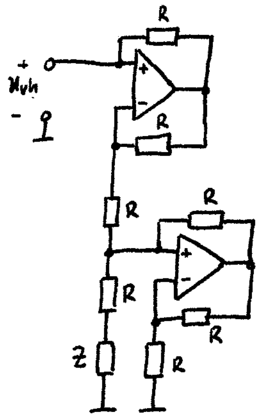
$$Z_{vh} = \frac{u_{vh}}{i_{vh}}$$

$$u_{vh} = u_2 \frac{Z}{R+Z}$$

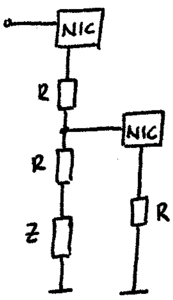
$$i_{vh} = \frac{u_{vh} - u_2}{R} = \frac{u_2 \frac{Z}{R+Z} - u_2}{R} = u_2 \frac{\frac{Z}{R+Z} - \underbrace{\frac{R+Z}{R+Z}}_{1}}{R} = u_2 \frac{-\frac{\cancel{R}}{R+Z}}{\cancel{R}} = -\frac{u_2}{R+Z}$$

$$Z_{vh} = \underline{\underline{-Z}}$$

- Girator (gyrator)
  inverzna impedanca



$\Rightarrow$

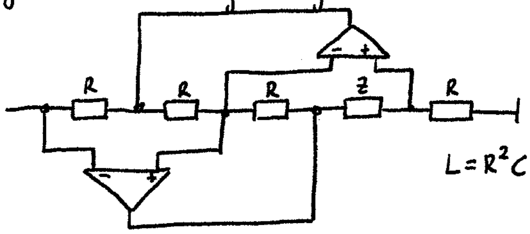


$$Z_{vh} = \Big[R + \underbrace{\big[(R+Z)\,||\,(-R)\big]}\Big] =$$

$$\neq \quad \frac{(R+Z)(-R)}{\cancel{R}+Z-\cancel{R}} = -\frac{R^2}{Z} - R$$

$$Z_{vh} = -\left[\cancel{R} - \frac{R^2}{Z} - \cancel{R}\right] = +\frac{R^2}{Z}$$

- Druga izvedba giratorja



$L = R^2 C$

23.5.2013

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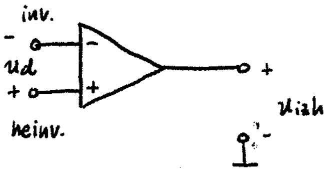
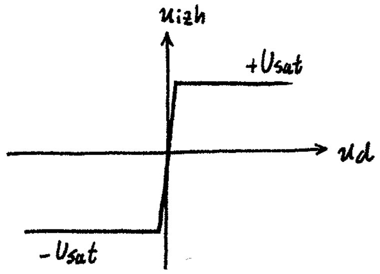
5. Napetostni komparatorji

(Voltage comparators)





če $u_d \overset{*}{>} 0 \longrightarrow u_{izh} = +U_{sat}$

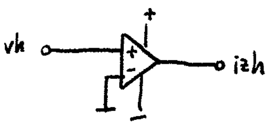
če $u_d \overset{*}{<} 0 \longrightarrow u_{izh} = -U_{sat}$

$* \ |u_d| > \frac{2U_{sat}}{A_0}$

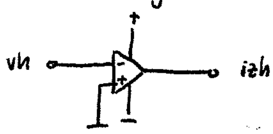
- komparatorji so ponavadi hitrejših od op-ampov pri preklapljanju od $-U_{sat}$ do $+U_{sat}$
- komparatorji nimajo kondenzatorja za stabilizacijo
- za hitrost čim več NPN tranzistorjev
- vhodne ničelne veličine večje kot pri op-ampih
- na vhodu se dovoli večja u_d
- na izhodu open-collector (ponavadi)

Detektor prehoda skozi ničlo

a) neinvertirajoči



b) invertirajoči

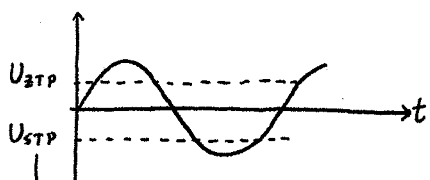


tule je lahko neka napetost, da detektiramo nek drug prag napetosti

če signal ni povsem gladek, se lahko zgodi, da komparator večkrat preklopi v okolici ničle

Komparator s histerezo

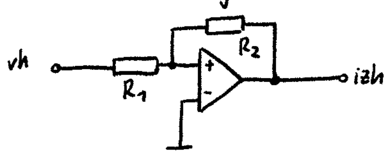
(schmidt-trigger)

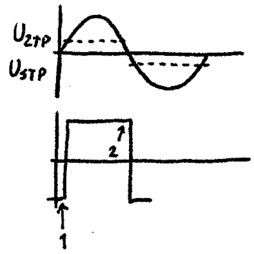


spodnja točka preklopa

uporabimo pozitivno povratno vezavo!

a) neinvertirajoči





izpeljava:

① pri preklopu $U_+ = U_- = 0\,V$

$U_{vh} = U_{ZTP}$

$U_{izh} = -U_{sat}$

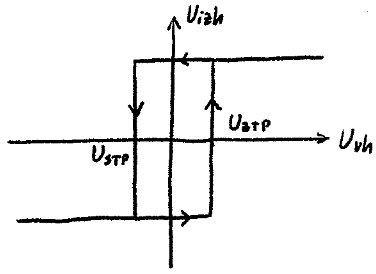
$\hookrightarrow \ U_{ZTP} = -\frac{R_1}{R_2}(-U_{sat})$

② pri preklopu $U_+ = U_- = 0\,V$

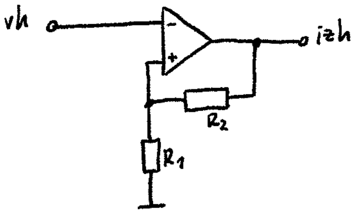
$U_{vh} = U_{STP}$

$U_{izh} = U_{sat}$

$\hookrightarrow \ U_{STP} = -\frac{R_1}{R_2}(U_{sat})$



b) invertirajoči



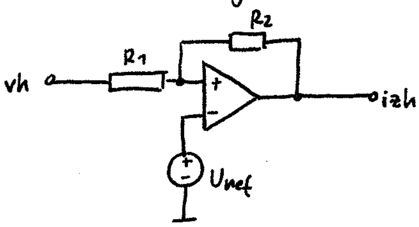
$$\underline{U_{ZTP} = \frac{R_1}{R_1+R_2}\left(+U_{sat}\right)}$$

$$\underline{U_{STP} = \frac{R_1}{R_1+R_2}\left(-U_{sat}\right)}$$

Komparator z nesimetrično histerezo

1) Uporaba U_{ref}

a) neinvertirajoči



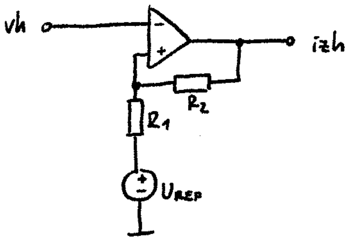
$$\underline{U_{ZTP} = -\frac{R_1}{R_2}\left(-U_{sat}\right) + \frac{R_1+R_2}{R_2}U_{REF}}$$

$$\underline{U_{STP} = -\frac{R_1}{R_2}\left(U_{sat}\right) + \frac{R_1+R_2}{R_2}U_{REF}}$$

sredinska točka

$$U_S = \frac{U_{ZTP}+U_{STP}}{2} = \frac{R_1+R_2}{R_2}U_{REF}$$

b) invertirajoči

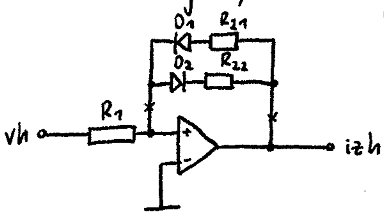


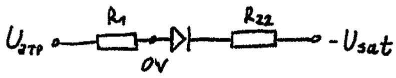
$$\underline{U_{ZTP} = \frac{R_1}{R_1+R_2}\left(+U_{sat}\right) + \frac{R_2}{R_1+R_2}U_{REF}}$$

$$\underline{U_{STP} = \frac{R_1}{R_1+R_2}\left(-U_{sat}\right) + \frac{R_2}{R_1+R_2}U_{REF}}$$

2) Uporaba diod

(neinvertirajoči)

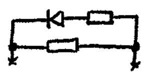


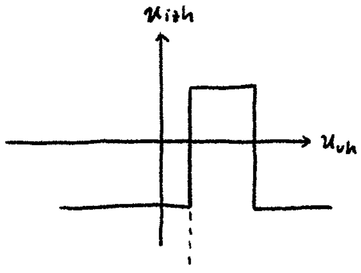


$$\hookrightarrow \underline{U_{ZTP} = -\frac{R_1}{R_{22}}\left(-U_{sat}+U_D\right)}$$

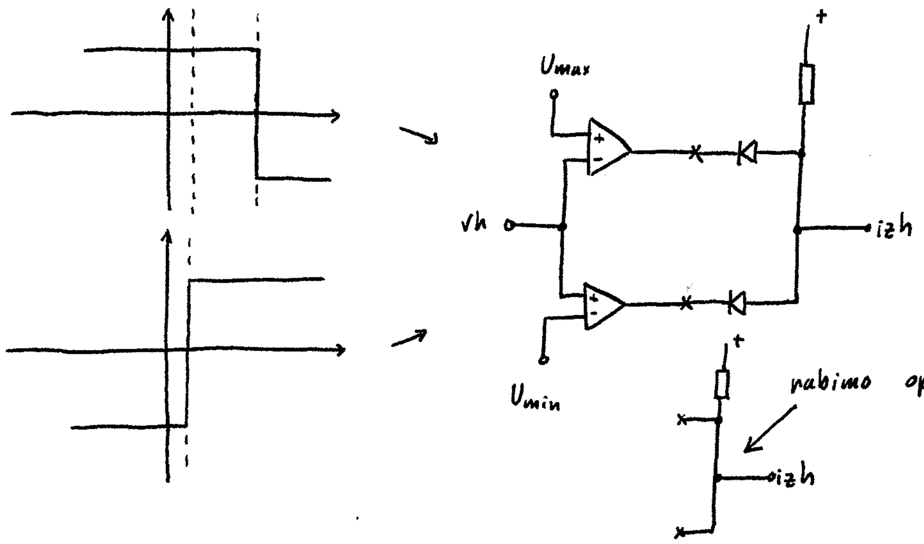
$$\underline{U_{STP} = -\frac{R_1}{R_{21}}\left(U_{sat}-U_D\right)}$$

opcija:





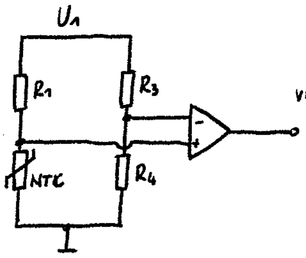
realiziramo z dvema



rabimo open-drain izhode!

Praktična uporaba komparatorjev

"Termostat"



visok izhod, ko temp nizka

6. Oscilatorji

30. 5. 2013

Texas Instruments "Chapter 15, Sine Wave Oscillators"

Generacija periodičnega izmeničnega signala konst. frek, ampl., oblike in pri tem na vhodu ni potreben noben vhoden signal!

<u>Signalni generator</u>: določena oblika signala, ampl. in frekv. lahko spreminjamo

<u>Funkcijski generator</u>: lahko spreminjamo tudi obliko signala, ...

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Osnovne izvedbe:

RC, $\underbrace{\text{LC, kvarčno-kristalni}}_{\text{višje frekvence}}$

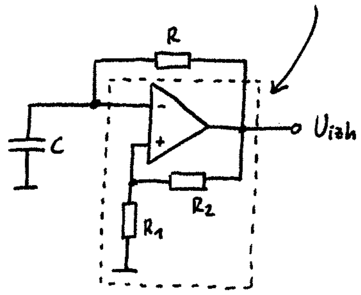
Delitev glede na način delovanja:

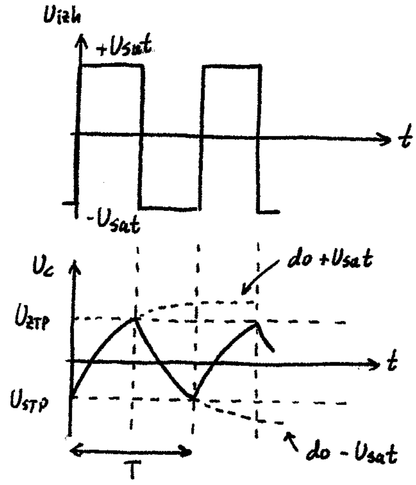
- relaksacijski (RC)
- sinusni (LC, quartz)

Relaksacijski oscilator

Generator pravokotnih pulzov:

izkoristimo komparator s histerezo (invertirajoč)



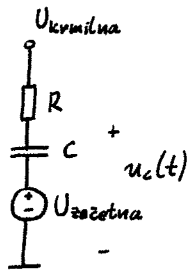


izraza za U_{ZTP} in U_{STP}:

$$U_{ZTP} = \frac{R_1}{R_1+R_2}\left(U_{sat}\right)$$

$$U_{STP} = \frac{R_1}{R_1+R_2}\left(-U_{sat}\right)$$

izračun R in C



$$u_c(t) = U_{zač} + (U_{krm} - U_{zač})\left(1 - e^{-\frac{t}{RC}}\right)$$

$0 \le t \le \frac{T}{2}$

$$u_c\left(\frac{T}{2}\right) = U_{ZTP} = U_{STP} + (U_{sat} - U_{STP})\left(1 - e^{-\frac{T}{RC\cdot 2}}\right)$$

$$-\left(\frac{U_{ZTP} - U_{STP}}{U_{sat} - U_{STP}} - 1\right) = e^{-\frac{T}{2RC}}$$

$$-\left(\frac{U_{ZTP} - \cancel{U_{STP}} - U_{sat} + \cancel{U_{STP}}}{U_{sat} - U_{STP}}\right) = e^{-\frac{T}{2RC}}$$

$$T = 2RC \cdot \ln \frac{U_{sat} - U_{STP}}{U_{sat} - U_{STP}}$$

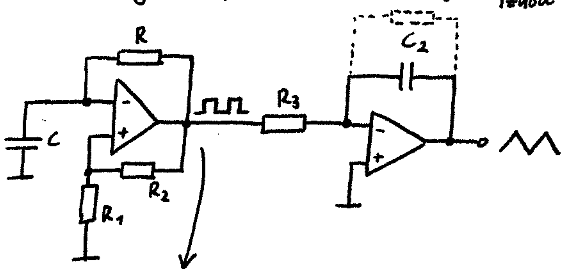
$$\boxed{T = 2RC \cdot \ln \frac{2R_1 + R_2}{R_2}}$$

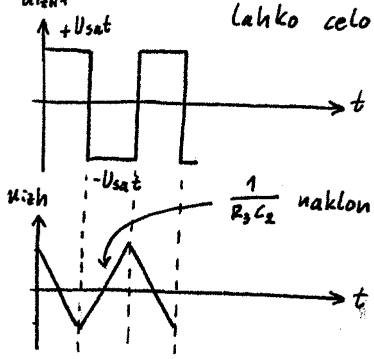
Generator trikotnega signala:

frekvenco določa levi komparator, amplituda izhoda desnega se spreminja zaradi različnega časa integriranja (naklon se ohranja), lahko celo preide v trapeznega

1) preko integratorja:

~10 R_3 da preprečimo da gre izhod v nasičenje





$$T = 2RC \ln \frac{2R_1+R_2}{R_2}$$

$$f_0 = \frac{1}{T}$$

$$U_{pp} < 2\,U_{sat}$$

$$U_{pp} = \left| \frac{-1}{R_3C_2} \int_0^{\frac{T}{2}} +U_{sat}\,dt \right| = \frac{U_{sat}\,T}{R_3C_2 \cdot 2} \longrightarrow T = \frac{2\,U_{pp}\,R_3C_2}{+U_{sat}}$$

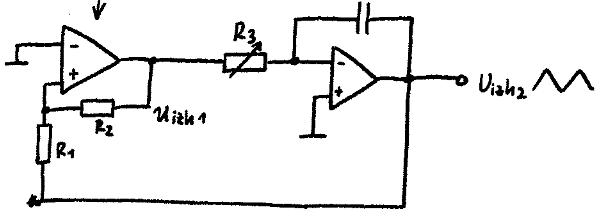
2 U_{sat}

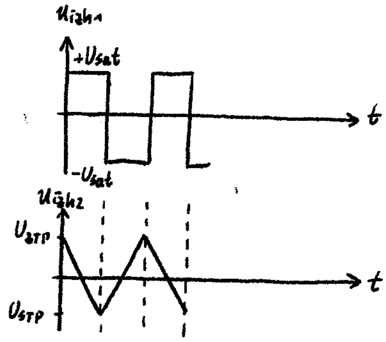
$$T_{max} = 4\,R_3C_2$$

sicer pride izhod integratorja v nasičenje

2) a

neinvertirajoč





besser!

amplituda se ohranja (določata R_1 in R_2), frekvenco določajo vsi R_1, R_2, R_3, C, če želimo spreminjati samo ~~amplitud~~ frekvenco, spreminjamo R_3 ali C

$$U_{ZTP} = -\frac{R_1}{R_2}(-U_{sat})$$

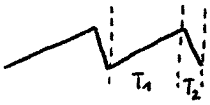
$$U_{STP} = -\frac{R_1}{R_2}(U_{sat})$$

$$U_{pp} = U_{ZTP} - U_{STP} = \left| -\frac{1}{R_3C} \int_0^{\frac{T}{2}} +U_{sat}\,dt \right| =$$

$$= \frac{U_{sat}}{R_3C} \cdot \frac{T}{2} \longrightarrow T = 2R_3C\,\frac{U_{ZTP}-U_{STP}}{U_{sat}}$$

$$T = 4 \cdot \frac{R_1R_3C}{R_2}$$

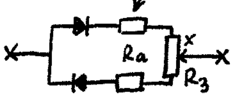
Generator žagastega signala



$T = T_1 + T_2$

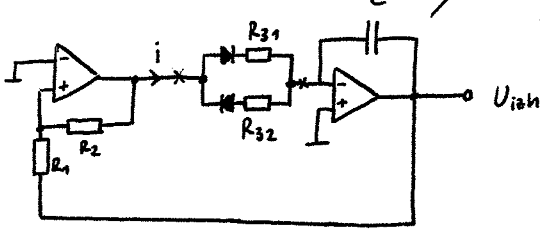
$D.C. = \frac{T_1}{T_1+T_2}$

if you're a wuss



$\longrightarrow$ $Ra + x \cdot R_3$

$\longleftarrow$ $Ra + (1-x)R_3$

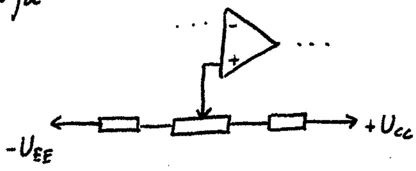


2) b

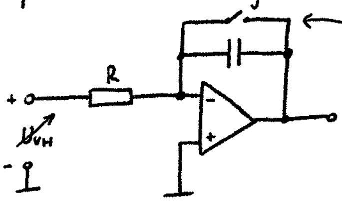
spreminjamo U^+ napetost levega komparatorja na prejšnjem vezju, (ne rabimo diod)
tako spreminjamo tok polnjenja kondenzatorja:

tok v desno: $i_1 = \frac{+U_{sat} - U_-}{R_3}$

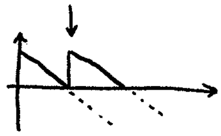
tok v levo: $i_2 = \frac{-U_{sat} - U_-}{R_3}$



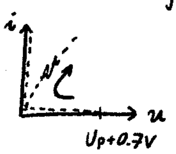
Napetostno krmiljen oscilator

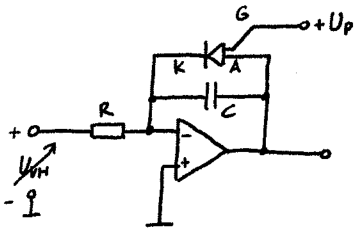


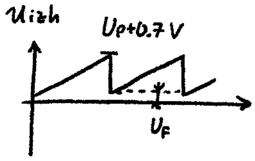
stikalo bi se moralo skleniti ob nekem pragu U_c



uporabimo element PUT
Programmable Unijunction Transistor

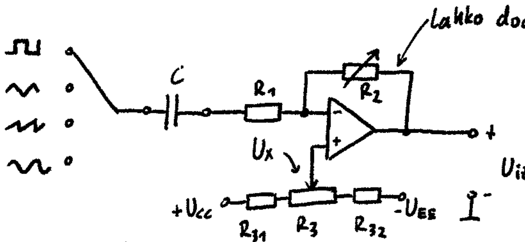






$$T = RC \frac{U_P + 0.7V - U_F}{|U_{VH}|}$$

Funkcijski generator



lahko dodamo še upor R_{22}

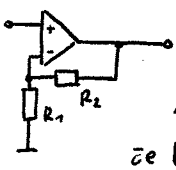
$A_u = -\frac{R_2}{R_1}$ $\qquad A_{umax} = -\frac{R_2 + R_{22}}{R_1}$

$A_{umin} = -\frac{R_{22}}{R_1}$

zaradi kondenzatorja imamo f_{min}

$$f_{min} = \frac{1}{2\pi R_{eq} C}$$

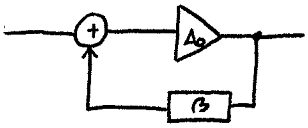
samo R_1 (+ R_{izh} osc.)



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

če bi želeli ojačanje 1 za offsetno napetost, mora recimo R_1 biti neskončen (za DC), dodamo kondenzator

Sinusni oscilatorji



$$A_\beta = \frac{U_{izh}}{U_{vh}} = \frac{A_0}{1-\beta A_0}$$

$$U_{izh} = \frac{A_0}{\underbrace{1-\beta A_0}} U_{vh}$$

če to postane 0, bo vezje zaosciliralo

$1-\beta A_0 \to 0$

$= 0$

$A_0 \beta = 1$

$A_0\beta(j\omega_0) = 1 + j0$ želeli bi, da to velja samo pri eni frekvenci

Barkhausen-ova kriterija:

1. amplitudni kriterij $|A_0\beta(j\omega_0)| = 1$
2. fazni kriterij $\arg A_0\beta(j\omega_0) = \varphi = 0 + 2k\pi$

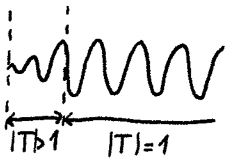
$|A_0\beta| = |T|$

$|T| = 1$

na začetku bi želeli $T > 1$

(da začne oscilirati)

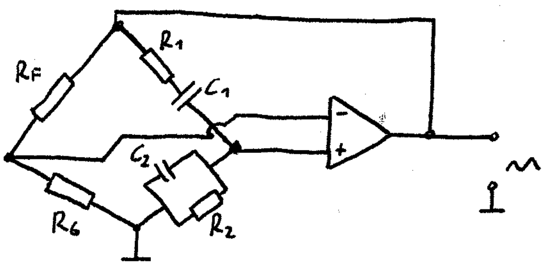
$T = 1$ je stacionarno stanje

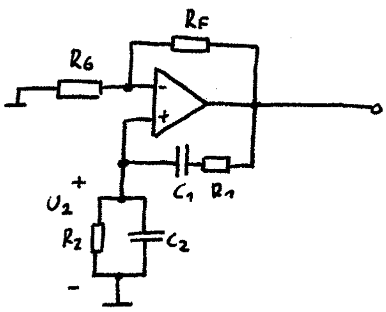


4.6.2013

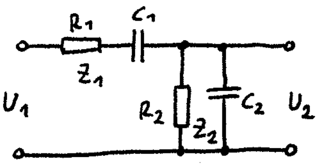
RC sinusni oscilator

1) Wien-ov mostični oscilator





samo povratna vezava:



$$H(j\omega) = \beta = \frac{U_2}{U_1} = \frac{Z_2}{Z_1+Z_2} = \dots = \frac{R_2 X_{C2}}{(R_1X_{C2} + R_2X_{C1} + R_2X_{C2}) + j(R_1R_2 - X_{C1}X_{C2})}$$

pogoj $\varphi = 0 + 2k\pi$ $\quad \varphi(\beta A) = 0°$

$$R_1R_2 - X_{C1}X_{C2}\Big|_{\omega=\omega_0} = 0 \Rightarrow R_1R_2 = \frac{1}{\omega_0 C_1}\cdot\frac{1}{\omega_0 C_2}$$

$$\omega_0 = \frac{1}{\sqrt{R_1R_2C_1C_2}}, \quad \omega_0 = \frac{1}{RC}$$

$R_1 = R_2 = R$

$C_1 = C_2 = C$

še drug pogoj:

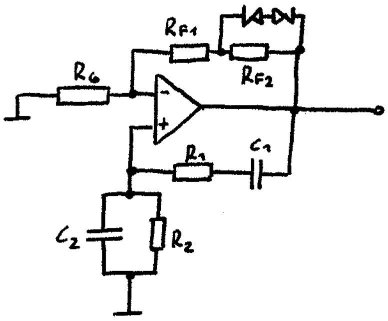
$|\beta A|_{\omega_0} = 1 \rightarrow A = 3$

$\beta_{\omega_0} = \frac{Z_2}{Z_1+Z_2} = \frac{R}{3R+j0} = \frac{1}{3}$

to bomo dosegli z negativno povratno zanko

$\cancel{\frac{R_F}{R_G} = A = 3}$ $\quad A = \frac{R_G+R_F}{R_G} = 3 \longrightarrow \underline{\underline{\frac{R_F}{R_G} = 2}}$

- vezje bo načeloma nihalo med $-V_{sat}$ in V_{sat}
- problem štarta oscilatorja (na začetku je dobro imeti $\beta A > 1$)



na začetku:

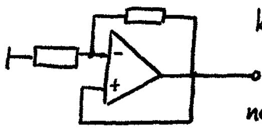
$R_{F1}+R_{F2} > 2 \cdot R_G$ (večje ojačanje)

pri oscilacijah:

$R_{F1} \leq 2 \cdot R_G$ (malce večja stabilnost)

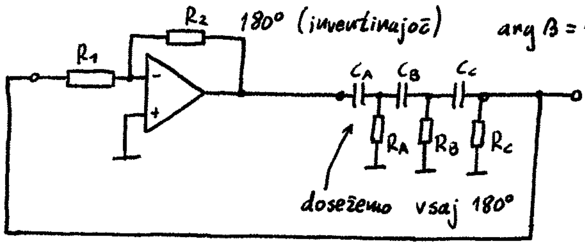
za štart lahko tudi pustimo R_F in namesto R_G damo nek PTC (npr tlivka)

2) Oscilator na osnovi faznega zasuka

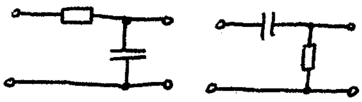


kljub fazi 0° → ne vemo kje zaoscilira!

- nimamo frekvenčne selektivnosti

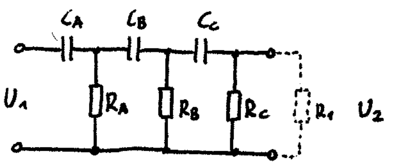


$\arg\beta = 180°$



$0 \div -90°$ $\quad$ $0 \div +90°$

rabimo 180°!



$R_A = R_B = R_C = R$

$C_A = C_B = C_C = C$

$$H(j\omega) = |\beta| = \frac{R^3}{(R^3 - 5RX_c^2) + j(X_c^3 - 6R^2X_c)}$$

$$X_c^3 - 6R^2X_c = \emptyset$$

$$\underline{\underline{\omega_0 = \frac{1}{\sqrt{6}\cdot R\cdot C}}}$$

$\varphi_{RC} = 180°$

$\arg(\beta A) = 180° + 180° = 360° + 2k\pi$

$|T| = |\beta A| = 1$

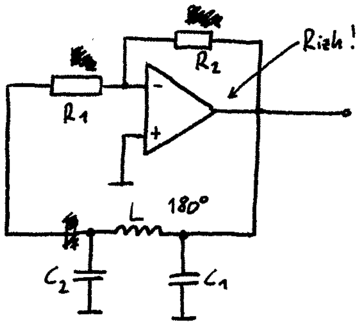
$$|\beta| = \frac{R^3}{R^3 - 5RX_c^2} = \frac{R^3}{R^3 - 30R^3} = \frac{1}{29}$$

$|A| = 29$ (invertirajoč)

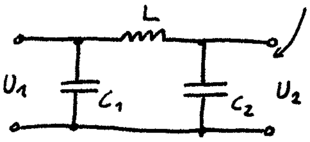
$$\underline{\underline{|A| = \frac{R_2}{R_1} = 29}}$$

LC sinusni oscilator

1) Colpittsov oscilator



tule je sicer še R_1, ampak rečemo $R_1 \gg X_{C2}$ (izberemo)



vezje oscilira pri resonančni frekvenci LC podvezja

$$Z(j\omega) = -jX_{C1} \parallel (jX_L - jX_{C2}) = \frac{X_L X_{C1} - X_{C1} X_{C2}}{j(X_L - X_{C1} - X_{C2})}$$

$$H(j\omega) = |\beta| = \frac{-jX_{C2}}{jX_L - jX_{C2}} =$$

$$= \frac{-jX_{C2}}{jX_{C1} + \cancel{jX_{C2}} - \cancel{jX_{C2}}} = -\frac{X_{C2}}{X_{C1}} = -\frac{C_1}{C_2}$$

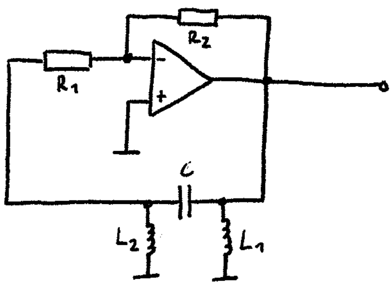
brez imaginarnega:

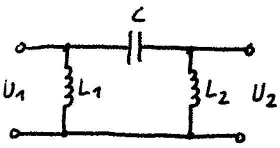
$$X_L - X_{C1} - X_{C2} = 0$$

$$\underline{\underline{\omega_0 = \frac{1}{\sqrt{L \frac{C_1 C_2}{C_1 + C_2}}}}}$$

$$A = \frac{1}{\beta} = \frac{C_2}{C_1} \longrightarrow \underline{\underline{\frac{R_2}{R_1} = \frac{C_2}{C_1}}}$$

2) Hartley-ev oscilator





$$Z(j\omega) = \ldots = \frac{jX_{L1}(jX_{L2} - jX_C)}{j(X_{L1} + X_{L2} - X_C)} \rightarrow = 0$$

$$\underline{\underline{\omega_0 = \frac{1}{\sqrt{(L_1 + L_2)C}}}}$$

$$H(j\omega) = \beta = \frac{jX_{L2}}{-jX_C + jX_{L2}}$$

$$|A| = \frac{L_1}{L_2} \qquad \underline{\underline{\frac{R_2}{R_1} = \frac{L_1}{L_2}}}$$

Kvarčni oscilator

glej liste

LC sinusni oscilator

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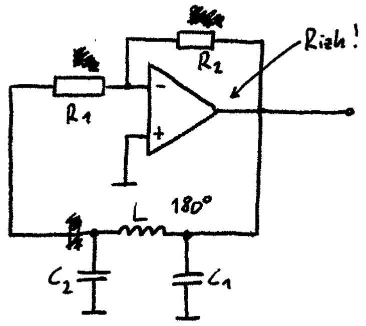

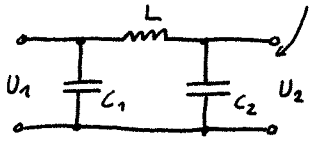

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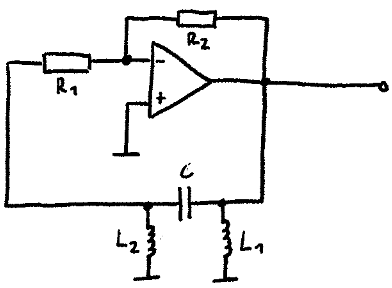

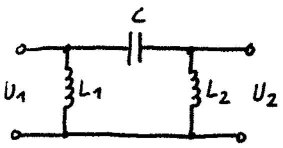

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Kvarčni oscilator

glej liste