# ELEKTRONIKA II

## 3

Zapiski z avditornih vaj

TK

| | |
|---|---|
| **Šolsko leto** | 2008/2009 |
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| | |
| **Avtor dokumenta** | Vesna Koderman |
| **Skeniranje** | Simon Kovše |

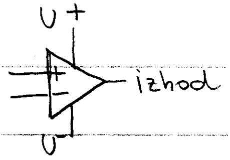
STROMAR.SI
DRUŠTVO ELEKTROTEHNIKOV

| UREJANJE DOKUMENTA | |
|---|---|
| **VERZIJA** | 01.01 |
| **DATUM** | 10.01.2010 |

**OPOMBE**

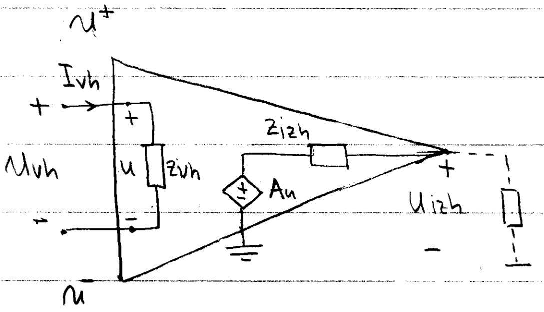
## ELEKTRONIKA - 2.del :

- ~ operacijski ojačevalnik
- ~ vezja z op.oj.
- ~ frekvenčna karakteristika op.oj.
- ~ lastnosti op.oj.



- SIMBOL ZA OP.OJ. :

↳ sešteva, odšteva, integrira analogne signale ... itd.



- Lastnosti, ki jih zahtevamo:

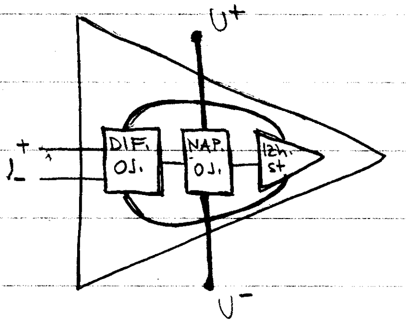
$Z_{vh}$ , $Z_{izh}$ , $A$

- Idealni op.oj.

- PREDPOSTAVIMO: $Z_{vh} = \infty$ , $Z_{izh} = 0$ $\Rightarrow$ $A \to \infty$

→ POSLEDICE: $I_{vh} = 0$ ; $U_{izh} = A \cdot u_{vh} = A(u^+ - u^-)$ ; $u_{vh} = 0 \Rightarrow u^+ = u^-$

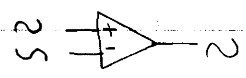
to sicer ni res, ampak predpostavimo, da gre za tako majhne napetosti, da so kar približno enake...



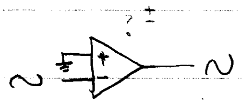
? DIFERENČNI

DIFERENCIALNI OJ. je poseben gradnik, ki ga redno srečamo na vhodu ... diferenco med vhodnima napetostima dobro ojača. Ponavadi je tri stopenjski ... na ta način zadostimo zgornjim zahtevam ...

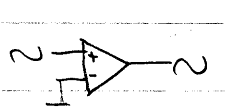
- DIF. VHOD :



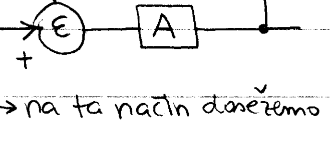
- INTERVIRAJOČI OJ. :



- NEINTERVIRAJOČI OJ :

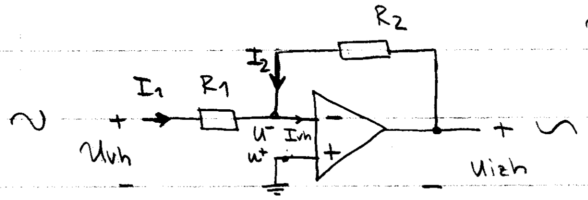


- POVRATNA VEZAVA :



↳ na ta način dosežemo boljše lastnosti !

## INTERVIRAJOČ OJAČEVALNIK:



⇝ imamo povratno zanko:

$R_1 = 1k\Omega$ ; $R_2 = 9k\Omega$

$I_{vh} = 0$ (to je vedno tako!)?

⇝ Na vhodu imamo nek signal majhne napetosti, kateremu ojačevalnik invertira fazo...

$U^+ = U^- = 0$ ... pomeni, da sta oba na masi

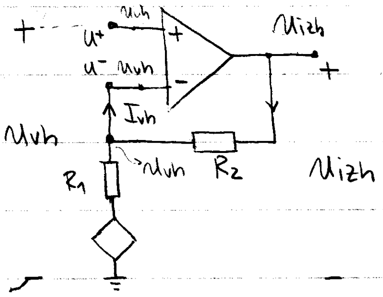
$I_1 + I_2 = I_{vh} \Rightarrow \frac{U_{vh}}{R_1} + \frac{U_{izh}}{R_2} = 0$ ... ker je $I_{vh} = 0$

$$\Rightarrow \boxed{U_{izh} = -\frac{R_2}{R_1} U_{vh}}$$

ojačanje je odvisno od razmerja uporov

$$\Rightarrow U_{izh} = \overset{?}{-}10\, U_{vh}$$

## NEINVERTIRAJOČ OJAČEVALNIK:



$I_{vh} = 0$

$U^+ = U^- = U_{vh}$

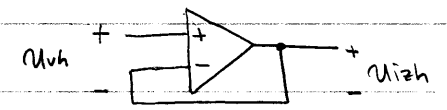
Lahko zapišemo kot napetostni delilnik: $\frac{U_{izh} - U_{vh}}{R_2} = \frac{U_{vh}}{R_1}$

$$\Rightarrow U_{izh} = \left(1 + \frac{R_2}{R_1}\right) \cdot U_{vh}$$

$R_2 = 9k\Omega$, $R_1 = 1k\Omega \Rightarrow U_{izh} = 10\, U_{vh}$

! ~ Povratne vezave moramo vedno risati v negativno sponko ...

$R_2 \mapsto 0$ , $R_1 \mapsto \infty$ : $u_{izh} = u_{vh}$

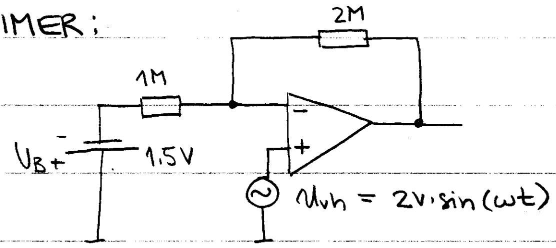


NAPETOSTNI SLEDILNIK :

- ojačanje ima vedno 1

$$-U_B \frac{R_2}{R_1} + u_{vh}\left(1+\frac{R_2}{R_1}\right)$$

PRIMER :



- enosmerni vir bomo obravnavali kot invertirajoč ojačevalnik, izmenični vir pa kot neinvertirajoči.

Izhodna napetost bo vsota obeh

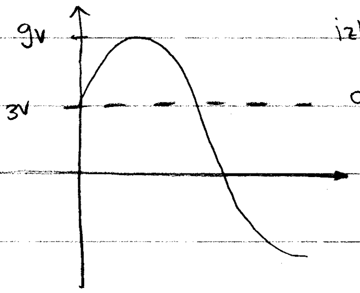
1.) $U_B = 0$ ... neinvertirajoč oj.

$\Rightarrow u_{izh_1} = (1 + 2/1)\cdot 2V\cdot\sin(\omega t) = 6V\cdot\sin(\omega t)$

2.) $U_B$ ; $u_{vh} = 0$ ... invertirajoč oj.

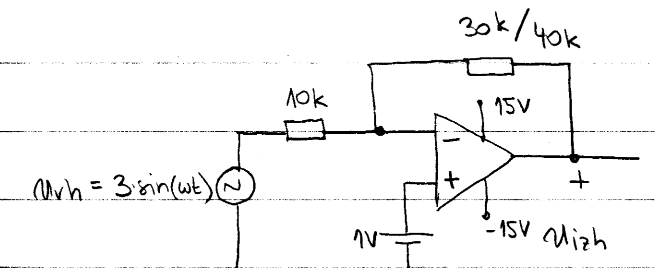
$\Rightarrow u_{izh} = -2/1\ (-1{,}5) = 3V$

ODGOVOR : $u_{izh} = 3V + 6V\sin(\omega t)$



izhod je omejen z napajalno napetostjo

PRIMER :



- $\underset{\sim\sim\sim}{u_{vh} = 0}$

30k : $u_{izh_1} = \left(1 + \frac{30}{10}\right)\cdot 1V = 4V$

40k : $u_{izh_1} = \left(1 + \frac{40}{10}\right)\cdot 1V = 5V$

- $\underset{\sim\sim\sim}{u_B = 0}$ :

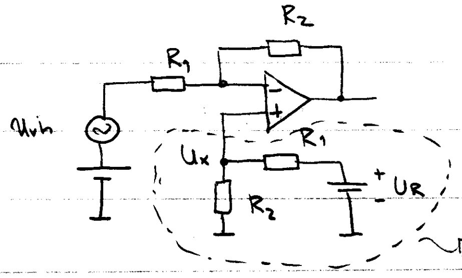
30k : $u_{izh} = -\frac{30}{40}\cdot 3\sin(\omega t) = -9V\cdot\sin(\omega t)$

40k : $u_{izh} = -\frac{40}{10}\cdot 3\cdot\sin(\omega t) = -12V\cdot\sin(\omega t)$

⟹ 30k : $u_{izh} = 4V - 9V \cdot \sin(\omega t)$ ; min: $-5V$ , max: $13V$

⟹ 40k : $u_{izh} = 5V - 12V \cdot \sin(\omega t)$ ; min: $-7V$ , max: $17V$

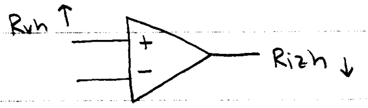
⇝



⇝ $u_x = \frac{R_2}{R_1+R_2} U_R$

$$\Rightarrow u_{izh} = -\underbrace{\frac{R_2}{R_1}\left(u_{vh} + U_R\right)}_{\text{v minus sponki}} + \left(1 + \frac{R_2}{R_1}\right)\left(\frac{R_2}{R_1+R_2}\right) U_R$$

4,3,2009



⇝ Ojačanje je tako veliko, da ga obravnavamo kot neskončno : $A_u \longmapsto \infty$

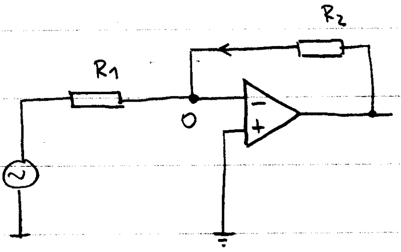
⇝ Rvh ↑ (visoka) ⟹ $R_{vh} \longmapsto \infty$

Rizh ↓ (čimnižja) ... to pomeni, da mora biti $i_{vh} = 0$

⇝ $R_{izh} \longmapsto 0$ ; $u_{izh} = A \cdot u_{vh}$ pri $A \mapsto \infty$

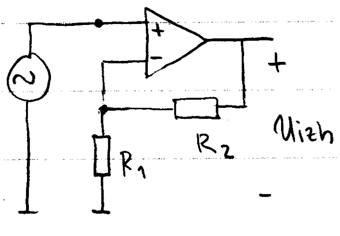
⟹ $u_{vh} = 0$ ; $u^+ = u^-$

• INVERTIRAJOČ OJ. :



$A_u = -R_2/R_1$

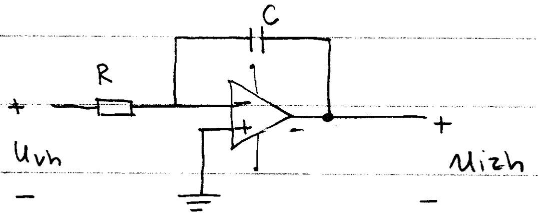
• NEINVERTIRAJOČ OJ :



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

- Kaj se zgodi, če namesto uporov dam noter kondenzator ... ⇒ premaknemo še v frekvenčni prostor

- Kako bi napisali napetostno ojačanje, če vezje izgleda takole:



⇒ To je **INTEGRATOR** ... v čas. prostoru integrira signal

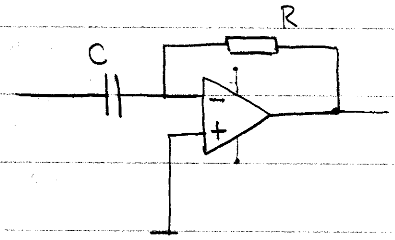
$$\left(A_u = -R_2/R_1\right) \rightsquigarrow \underbrace{A_u = -\frac{Z_2}{Z_1}}$$

namesto upornosti imamo inpendance

$$A_u = -\frac{1}{j\omega CR} = \frac{U_{izh}}{U_{vh}} \Rightarrow \boxed{U_{izh} = -\frac{1}{j\omega RC} \cdot U_{vh}}$$

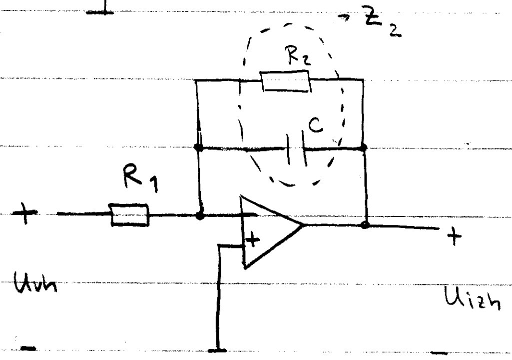
- Kaj se zgodi, če zamenjam upor in kondenzator ?

⇒ **DOBIMO DIFERENCIATOR** (v časovnem prostoru odvaja signal)



$$A_u = -\frac{R}{1/j\omega C} = -j\omega RC$$

**PRIMER:**



$$Z_2 = \left(\frac{1}{R_2} + j\omega \overset{R_2/R_2}{C}\right)^{-1} = \left(\frac{1+j\omega CR_2}{R_2}\right)^{-1} = \underbrace{\frac{R_2}{1+j\omega CR_2}}$$

integrator

$$\Rightarrow A_u = -Z_1/Z_2 = \frac{-R_2/R_1}{1+j\omega CR_2}$$

$$= -\frac{R_2}{R_1} \cdot \frac{1}{j\omega CR_2} = \overset{R_2/R_1}{}$$

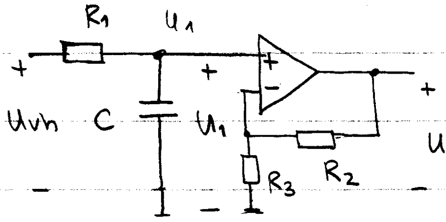
$\omega_p^{-1}$

$$\Rightarrow \omega_p = \frac{1}{R_2 C}$$

$$A_u = -Z_2/Z_1 = -\frac{R_2/R_1}{1+j\omega CR_2}$$

$$Z_2 = \left(\frac{1}{j\omega C} + \frac{1}{R_2}\right)^{-1} = \cancel{\frac{R_2 + j\omega C}{j\omega CR_2}} \left(\frac{j\omega CR_2 + 1}{R_2}\right)^{-1} = \frac{R_2}{1+j\omega CR_2}$$

**PRIMER:**



→ Diferenciator :

$$= \frac{U_{izh}}{U_1} = 1 + \frac{R_2}{R_3}$$

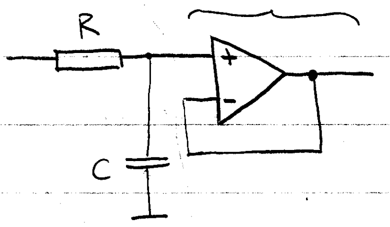
$$U_1 = U_{vh} \frac{1/j\omega c}{R_1 + 1/j\omega c} = U_{vh} \frac{1}{R_1 j\omega c + 1}$$

$$\underbrace{A_u = \left(1 + \frac{R_2}{R_3}\right) \frac{1}{j\omega C R_1 + 1}}$$

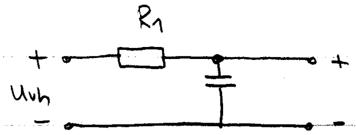
$$U_{izh} = U_1 \left(1 + \frac{R_2}{R_3}\right) = \frac{U_{vh}}{1 + R_1 j\omega c} \left(1 + \frac{R_2}{R_3}\right)$$

$$A_u = (1 + R_2/R_3) = 1$$

⤳



$R_2 \longrightarrow 0$ ; $R_3 \longrightarrow \infty$



nizkopasovno sito:

pri visokih f. je kondenzator kratek stik, pri nizkih f. pa odprte sponke.

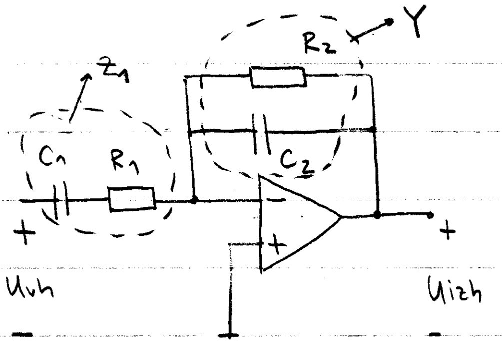
$$Z_1 = \frac{1}{j\omega C_1} + R_1 =$$

$$= \frac{1 + j\omega C_1 R_1}{j\omega c}$$

$$Z_2 = \left(\frac{1}{R_2} + j\omega C_2\right)^{-1} =$$

$$= \frac{R_2}{j\omega C R_2 + 1}$$

**PRIMER:**



$$Y_2 = \overset{\overset{1/R_2}{\parallel}}{G} + j\omega C_2 = \frac{1}{R_2} + j\omega C_2$$

$$Z_1 = R_1 + \frac{1}{j\omega C_1} = \frac{j\omega C_1 R_1 + 1}{j\omega C_1}$$

$$Z_2 = 1/Y$$

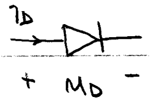
$$\Rightarrow \underbrace{A_u = -\frac{R_2}{\left(R_1 + \frac{1}{j\omega C_1}\right)(1 + j\omega C R_2)}} ; \checkmark$$

$$A_u = -Z_2/Z_1 = \frac{-R_2}{1 + j\omega R_2 C_2} \cdot \frac{j\omega C_1}{(1 + j\omega C_1 R_1)}$$

$$A_u = -Z_2/Z_1 = -\frac{R_2}{j\omega C_2 R_2 + 1} \cdot \frac{j\omega C_1}{1 + j\omega C_1 R_1} = -$$

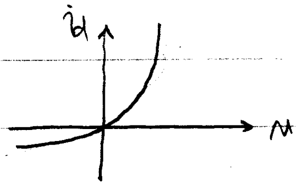
# Avditorne vaje

**DIODA:**

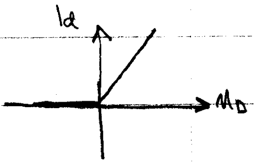


Dioda ... za negativne napetosti ne prevaja, za pozitivne pa predstavlja kratek stik:

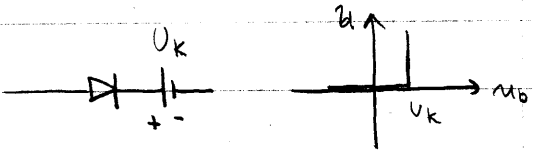
- Karakteristika idealne diode:



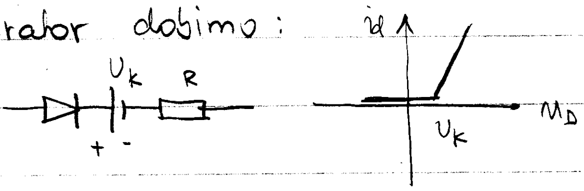
- Če tej idealni diodi dodamo upor dobimo naslednjo karakteristiko:



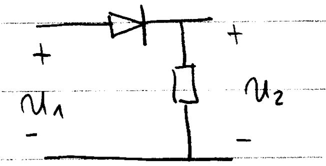
- Če diodi dodamo generator dobimo:



- Če diodi dodamo upor in generator dobimo:



1.) Imamo vezje:



a) $u_1 > 0$ (če je dioda idealna)

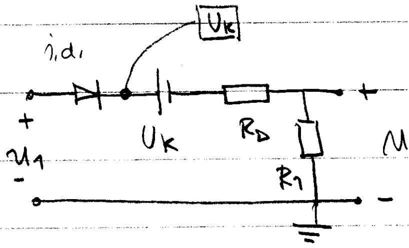
▷| kratek stik

$\Rightarrow u_2 = u_1$

b) $u_1 < 0$ (dioda in upor)

$u_2 > 0$ ( ▷| odprte sponke,

2.) Zanima nas vpliv $U_K$ in $R_D$:



a) $u_1 > u_K$

▷| : k.s.

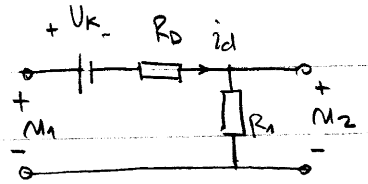
Če želimo izvedeti, koliko je $U_2$, moramo rešit vezje ⇒ na drugi strani

b) $u_1 < U_K$

▷| : o.s.

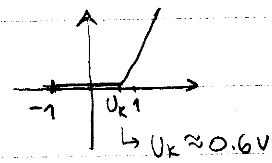
$\Rightarrow u_2 = 0$

→ 1.a)

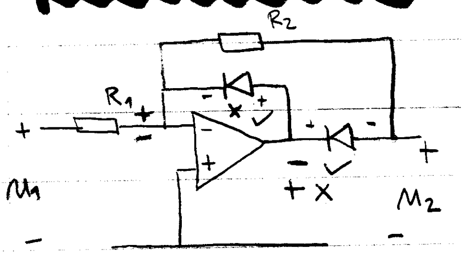


... sama določi $u_2$ iz vezja!

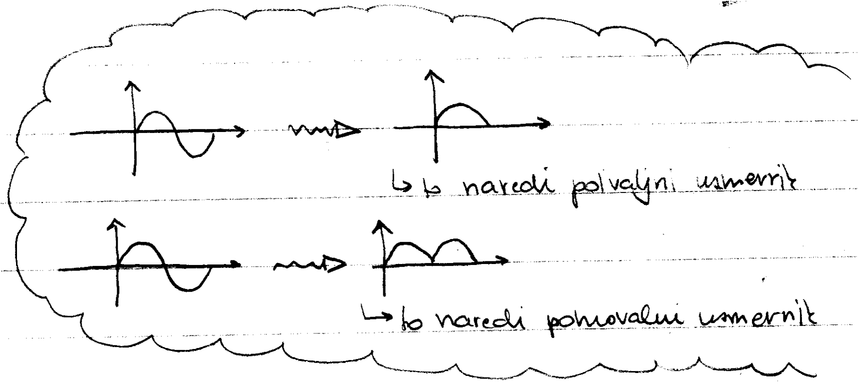
... dobimo: $u_2 = \frac{(u_1 - U_K) R_1}{R_1 + R_D}$ ; če je $R_1 >> R_D$ potem: $u_2 = u_1 - U_K$



## • Polvalni usmernik:



↳ imamo idealni diodi!



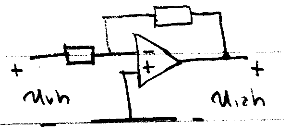
↳ bo naredi polvalni usmernik

↳ bo naredi polnovalni usmernik

→ Ti dve diodi bosta vedno v kontra delovanju. Če bo ena prevajala bo druga zaprta...

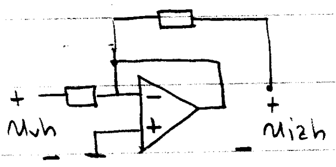
a) $u_{vh} > 0$

- dobimo invertirajoč ojačevalnik:



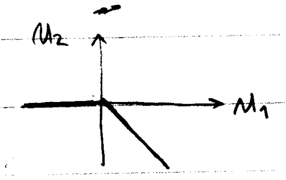
$$\Rightarrow u_2 = u_{izh} = -\frac{R_2}{R_1} u_1 \Big|_{R_1 = R_2 = R} = -u_1$$

b) $u_{vh} < 0$ ; dobimo:

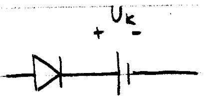


$\Rightarrow u_2 = 0$

- Karakteristika polvalnega usmernika:

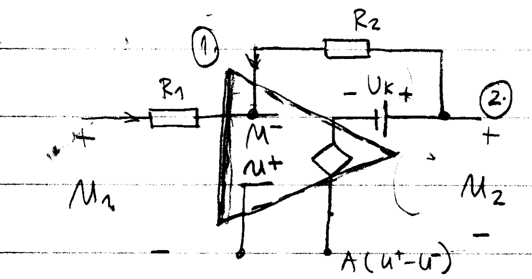


* Če imamo poleg diode še generator:



– Kako to vpliva na napetost na izhodu?

$u_{izh} = ?$



⇝ Vpliv kolena diode na vezje:

① $\frac{u_1 - u^-}{R_1} + \frac{u_2 - u^-}{R_2} = 0$

↳ $u^-$ (izrazimo)

② $u_2 = A(\overset{0,\text{ker je na masi...}}{u^+} - u^-) + U_k =$

$= -A \cdot u^- + U_k$

Definicija

$\frac{u_1}{R_1} + \frac{u_2}{R_2} - u^-\left(\frac{1}{R_1} + \frac{1}{R_2}\right) = 0$

$\Rightarrow \quad u^- = \left(\frac{u_1}{R_1} + \frac{u_2}{R_2}\right) \cdot \frac{R_1 \cdot R_2}{R_1 + R_2} = \frac{R_2 \cdot u_1 + R_1 u_2}{R_1 + R_2}$

$\Rightarrow \quad u_2(u_1) = -A \cdot \frac{R_2 u_1 + R_1 \cdot u_2}{R_1 + R_2} + U_k$

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

$\Rightarrow \quad u_2\left(1 + \frac{A \cdot R_1}{R_1 + R_2}\right) = U_k - A\frac{R_2 u_1}{R_1 + R_2}$

$\boxed{\begin{matrix} R_2 \mapsto 0 \\ (1+A) \approx A \end{matrix}}$

če to upoštevamo dobimo $u_2 \cong \frac{u_k}{A}$

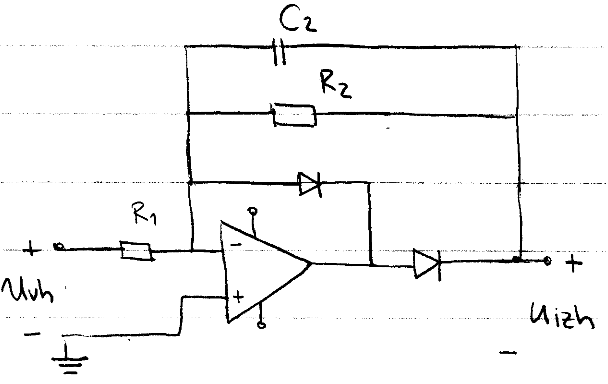
$\Rightarrow \quad u_2\left(\frac{R_1 + R_2 + A \cdot R_1}{R_1 + R_2}\right) = \frac{U_k(R_1 + R_2) - A \cdot R_2 u_1}{R_1 + R_2} \Rightarrow u_2 = \frac{U_k(R_1 + R_2) - AR_2 u_1}{R_1 + R_2 + A \cdot R_1}$

$\Rightarrow \quad u_2 = \frac{U_k(R_1 + R_2) - A \cdot R_2 \cdot u_1}{R_1(1 + A) + R_2} = \frac{U_k(R_1 + R_2)}{\cancel{R_1} + R_2 + A \cdot R_1} - \frac{AR_2 \cdot u_1}{\cancel{R_1} + R_2 + A \cdot R_1}$

$u_2 = -\frac{\overset{=0}{R_2}}{R_1}u_1 + \frac{u_k(R_1 + \overset{=0}{R_2})}{AR_1} = \underbrace{u_k/A}$

## Detektor srednje vrednosti:

↳ enako kot polvalni usmernik, le da imamo vezan še nek kondenzator (glej vajo 11!)



$\gamma = \frac{U_\approx}{U_{SR}}$ (po času $T_1$ je izh. nap.

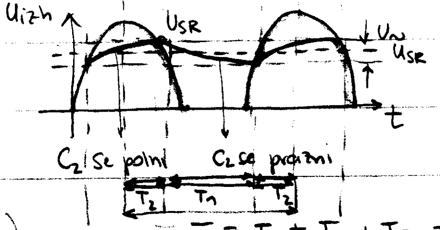
za $U_\approx$ manjša od $U_{SR}$: $\gamma = \frac{U_{sr} - U_{sr} \cdot 0.06}{U_{sr}}$ ... glej list!)

- Če vezju polvalnega usmernika dodamo kapacitivnost C, ki je vzporedno priključena k uporu $R_2$, dobimo detektor srednje vrednosti:

Naloga:

- Izračunajte C tako, da bo valovitost izh. nap. pri frekvenci 100kHz približno 6% srednje vrednosti izhodnega signala:

$$\delta = \frac{U_\approx}{U_{SR}} = 0{,}06$$



$$T = T_1 + T_2 + T_2 = T_1 + 2T_2$$

(naredili bomo dosti poenostavitev:)

$$u_{izh} = U_{SR} = U_C = I_{SR} \cdot R_2 = R_2 \cdot \frac{1}{2\pi}\int_0^\pi \sin(\omega t)\, d\omega t = \frac{U_m}{\pi} \cdot \frac{R_2}{R_1}$$

$U_m$ ... amplitude vhodne napetosti

- $T_2$ določimo s poenostavitvijo, da je $u_{izh}$ v točki $T_2$ kar $U_{SR}$

$$u_{izh} = U_{SR} = \frac{U_m}{\pi} \cdot \frac{R_2}{R_1} = U_m \cdot \frac{R_2}{R_1} \cdot \cos(\omega T_2) \Rightarrow \omega T_2 = \arccos\left(\frac{1}{\pi}\right) = \Theta$$

$$T_2 = \frac{\pi}{180^\circ} \cdot \frac{\Theta}{2\pi f} = \frac{\arccos\left(\frac{1}{\pi}\right)}{180^\circ \cdot 2 \cdot f} = 2ms$$

$$T = \frac{1}{f} = \frac{1}{100}\,Hz = 0{,}01\,s \Rightarrow T_1 = T - 2 \cdot T_2 = 6ms$$

$T_1$ ... čas praznjenja kondenzatorja

~ Po času $T_1$ je izh. napetost za $U_\approx$ manjša od $U_{SR}$:

$$U_{SR} \cdot e^{-T_1/R_2C_2} = U_{SR}(1-\delta) \Rightarrow e^{-T_1/R_2C_2} = (1-\delta)$$

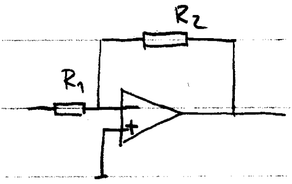
$$\Rightarrow \frac{T_1}{C_2R_2} = \ln 0{,}94 \Rightarrow C_2 = \frac{T_1}{R_2 \cdot \ln 0{,}94} \cong \underbrace{25\mu F}$$

- $u_{izh} = \frac{U_m}{\pi} \cdot \frac{R_2}{R_1} = \underbrace{1{,}24V}$ ... izhodna napetost v okviru časovne analize

Avd. vaje ... 25. 3. 09

1.) Zanima nas izraz za invertirajoč oj. : (ojačanje)

$A = -100$ ; $R_{vh} = 50k\Omega = R_1$

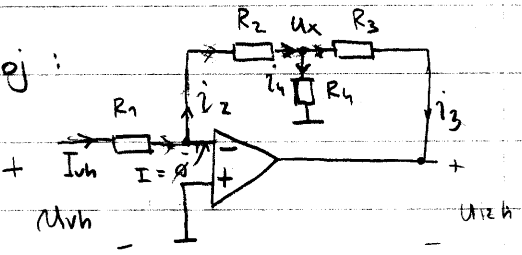


$$A = \frac{U_{izh}}{U_{vh}} = -\frac{R_2}{R_1} \Rightarrow R_2 = -R_1 \cdot A = -R_{vh} \cdot A = -50k\Omega \cdot -100 = \underbrace{5M\Omega}$$ ✓

problem je, da je ta upor pre-velik!

to vezje prinaša rešitev

2.) Zanima nas izraz za ojačanje naslednjega oj :



$$A = \frac{U_{izh}}{U_{vh}} = -\frac{R_2}{R_1} R_3 \left(\frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}\right) -$$

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

$- \frac{U_{iz}}{R_2}$

$i_2 - i_3 - i_4 = 0$

$-\frac{U_x}{R_2} - \frac{U_x}{R_4} + \frac{(U_x - U_{izh}}{R_3} = 0$

$\frac{U_{izh}}{R_3} = U_x\left(\frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}\right)$ ;

$i_2 = \frac{-U_x}{R_2}$

$U_{vh} = U_x\left(-R_1/R_2\right)$

~Torej lahko dobimo enak / podoben invertirajoč ojačevalnik, tudi če imamo dosti manjše upore.

npr. $R_2 = 500k\Omega$

$R_3 = 500k\Omega$

$R_4 = 62{,}5k\Omega$

$R_1 = 50k\Omega$

... $A = -100$ ... tako kot v 1. nalogi

Pomožne enačbe:

$i_3 = (U_x - U_{izh}) \cdot \frac{1}{R_3}$

$U_x = 0 - i_2 R_2$ ; $i_{vh} = \frac{U_{vh}}{R_1} = i_2$ ↓ $U_{vh} = i_2 \cdot R_1$

$i_2 = i_3 + i_4$

$i_4 = \frac{U_x}{R_4}$

$i_2 = \frac{U_x - U_{izh}}{R_3} + \frac{U_x}{R_4}$

$-\frac{U_x}{R_2} = \frac{U_x}{R_3} - \frac{U_{izh}}{R_3} + \frac{U_x}{R_4}$

$\frac{U_{izh}}{R_3} = U_x\left(\frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}\right)$

$\Rightarrow \underbrace{U_{izh} = U_x\left(\frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}\right) \cdot R_3}$

$U_x = \frac{-R_2}{R_1} \cdot U_{vh}$

$-\frac{U_{vh}}{R_1} - \frac{0 - U_x}{R_2} = 0$

$-U_{vh} \cdot \frac{R_2}{R_1} = U_x$

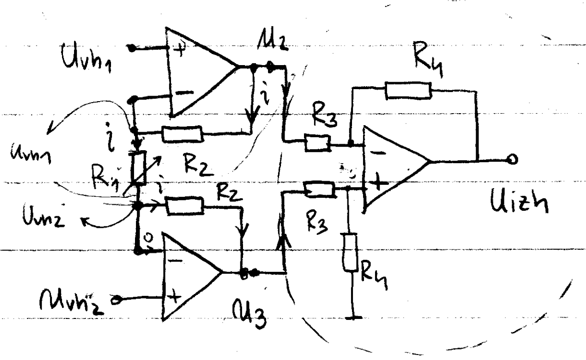
$$U_2 = U_{vh_1}\cdot\left(1+\frac{R_2}{R_1}\right) - \frac{R_2}{R_1}\cdot U_{vh_2}$$

$$U_3 = U_{vh_2}\left(1+\frac{R_2}{R_1}\right) - \frac{R_2}{R_1}U_{vh1}$$

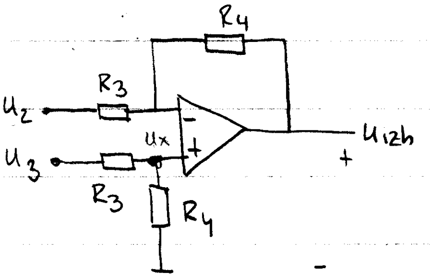
## Instrumentacijski ojačevalnik

3.) Imamo vezje:

↳ to vezje uporabljamo, kadar želimo ojačati drobne diferencialne vhode ... npr. tako deluje ojačanje za EKG.



~ To rešimo tako, da pogledamo najprej desni del vezja:



$$U_x = \frac{U_3\cdot R_4}{R_3+R_4}$$

$$\frac{R_4+R_2}{R_3}$$

$$U_{izh} = \underbrace{-\frac{R_4}{R_3}\cdot U_2}_{\text{pride od invert. oj.}} + \underbrace{\left(1+\frac{R_4}{R_3}\right)\cdot\frac{R_4}{R_3+R_4}\cdot U_3}_{\text{ta del pride zaradi } U_x} =$$

=

$$U_{izh} = (U_3 - U_2)\frac{R_4}{R_3}$$

~ Sedaj rešimo še levi del ojačevalnika:

$$\boxed{i = \frac{U_{vh1}-U_{vh2}}{R_1}}$$ reši do končnega izraza!

Razmerje elementov mora biti enako: $\boxed{\frac{R_4}{R_3} = \frac{R_2}{R_1}}$, če je $U_{vh1} = U_{vh2}$

→ $U_{izh} = 0$

$U_{izh1} = U_2$ , $U_{izh2} = U_3$

// ?  // ?

$$U_{izh1} = U_2 = U_{vh1} + iR_2$$

$$U_{izh2} = U_3 = U_{vh2} - iR_2$$

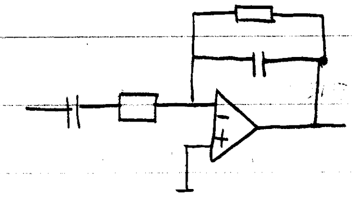
$$U_{izh1} = U_{vh1} + \frac{U_{vh1}-U_{vh2}}{R_1}R_2 = \ldots$$

$$U_{izh2} = U_{vh2} - \frac{U_{vh1}-U_{vh2}}{R_1}\cdot R_2 = \ldots$$

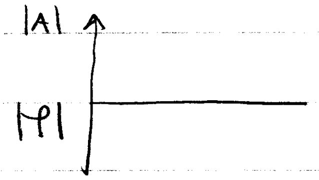
$$\Rightarrow U_{izh1} = \left(1+\frac{R_2}{R_1}\right)U_{vh1} - \frac{R_2}{R_1}U_{vh2}$$

$$\Rightarrow U_{izh2} = \left(1+\frac{R_2}{R_1}\right)U_{vh2} - \frac{R_2}{R_1}U_{vh1}$$

## Analiza v frekvenčnem prostoru:

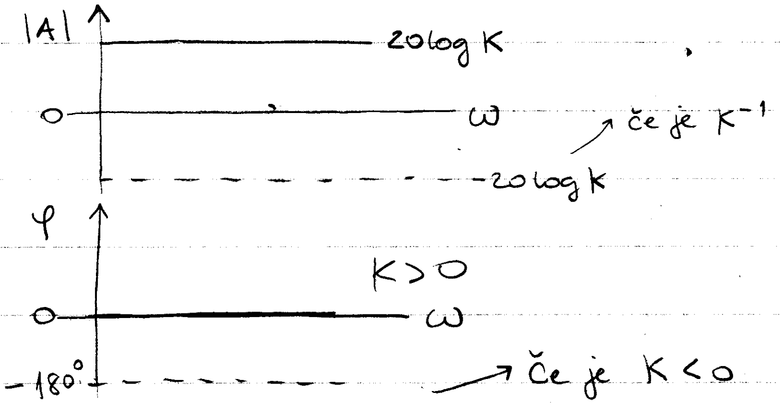


$$A(j\omega) = K \frac{j\omega\,(1+j\omega/\omega_N)}{j\omega\,(1+j\omega/\omega_p)}$$

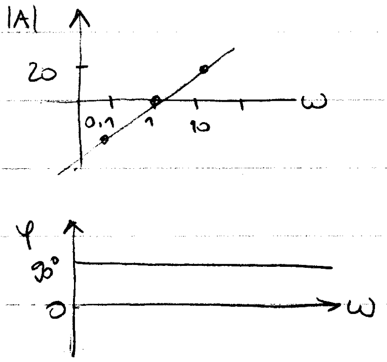


Bodejev diagram!

1. ~ Konstantno ojačanje:



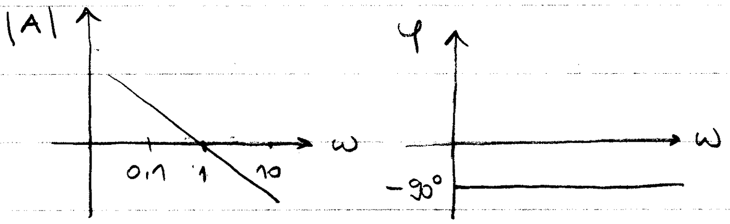
2. ~ Diferencialni oj.: jω



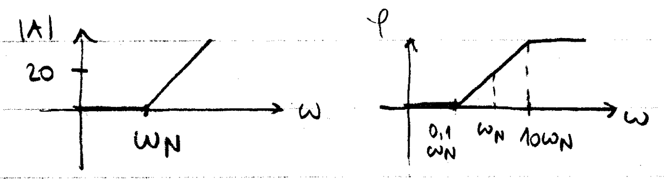
$A(j\omega) = j\omega$

3. ~ Integrirni element:

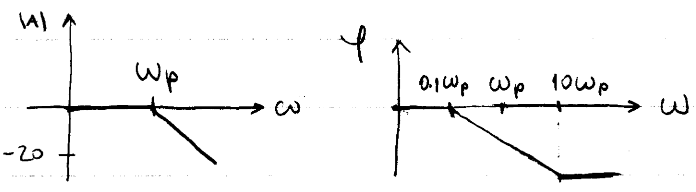
$$\frac{1}{j\omega}$$



4. ~ Ničla: $(1+\frac{j\omega}{\omega_N})$

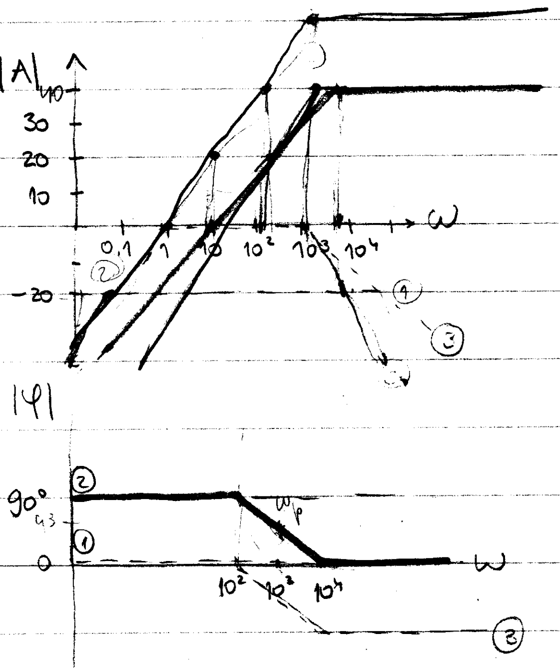


5. ~ Pol: $(1+\frac{j\omega}{\omega_p})$



PRIMER:

$$A(j\omega) = \frac{\overset{①}{0{,}1}\ \overset{②}{j\omega}}{1+j\frac{\omega}{10^3}} \rightarrow ③ \implies$$



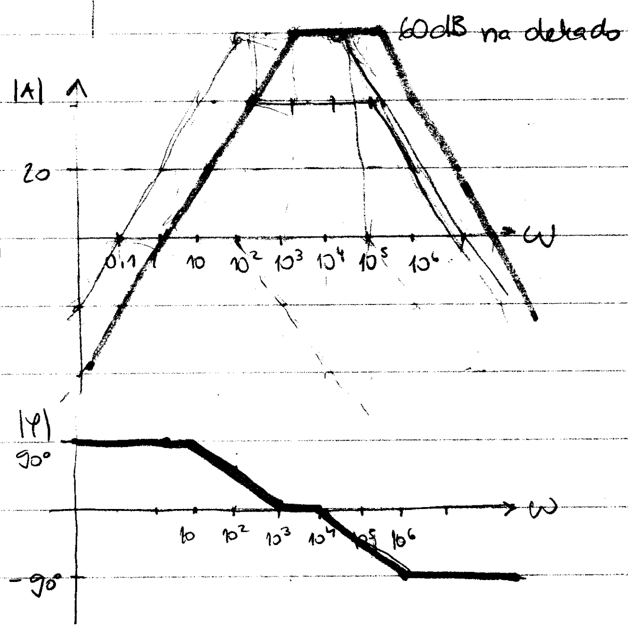
— potek amplitude

— potek faze

- Sešteti moramo ①, ② in ③

PRIMER:

$$A(j\omega) = \frac{10\,j\omega}{\left(1+j\frac{\omega}{10^2}\right)\left(1+\frac{j\omega}{10^5}\right)}$$



— amplitudni potek

— fazni potek

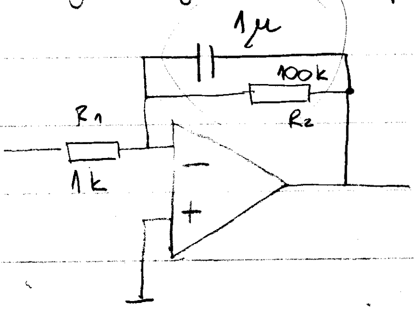
Domača naloga;

nariši bodejev diagram

za prejšnje primere (diferenciator / integrator)

## Avditorne vaje:

1.) Nariši bodejev diagram za spodnji ojačevalnik



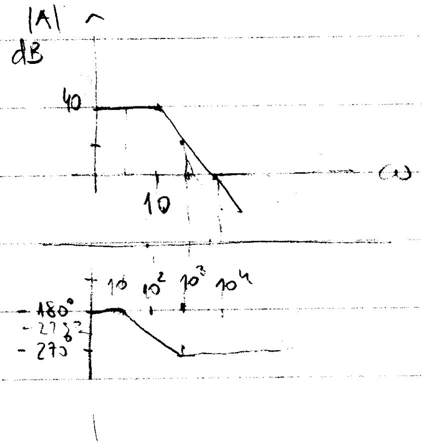
=> integrator

$$A_u = \frac{R_2 / R_1}{1 + j\omega C R_2} =$$

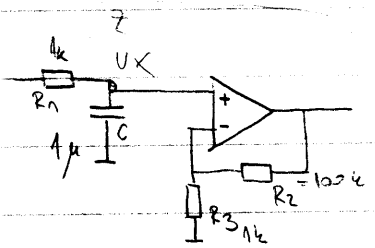
$$= \frac{-100}{1 + j\omega/10}$$

$\omega_p = 10$

$$\left(j\omega C + \frac{1}{R_2}\right)^{-1} = \frac{R_2}{1 + j\omega C R_2}$$



2.) Nariši bodejev diagram za:



$$A = \left(1 + \frac{R_2}{R_3}\right)\frac{1}{j\omega R_1 C + 1} = \frac{101}{1 + j\omega/10^3}$$

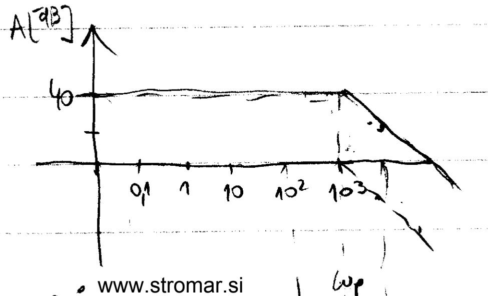
$$\left(1 + \frac{R_2}{R_3}\right) U_x = U_{izh}$$

$$R_1 \| C = Z = \left(\frac{1}{R_1} + j\omega C\right)^{-1}$$

$$U_x = U_{vh} \cdot \frac{\frac{1}{j\omega C}}{\frac{1}{j\omega C} + R_1} = U_{vh} \frac{1}{1 + R_1 j\omega C}$$

$$U_{izh} = U_{vh} \left(1 + \frac{R_2}{R_3}\right)\left(\frac{1}{1 + R_1 j\omega C}\right) =$$

$$A = \frac{101}{1 + \frac{j\omega}{10^3}}$$

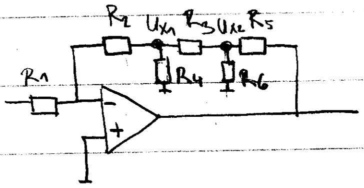


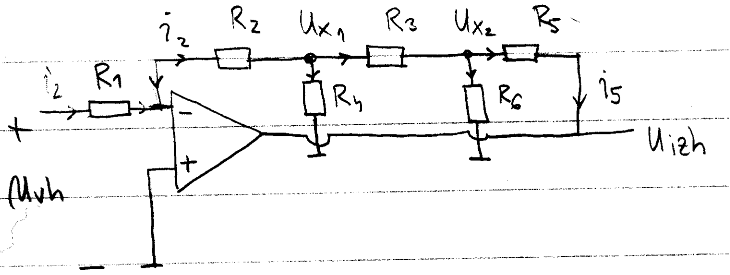
- Končni izraz za primer 3, ko imamo sestavljeno vezje iz treh oj:

$$\Rightarrow U_{izh} = \frac{R_4}{R_3}\left[\left(1+\frac{R_2}{R_1}\right)U_{vh2} - \frac{R_2}{R_1}\cdot U_{vh1} - \left(1+\frac{R_2}{R_1}\right)U_{vh1} + \frac{R_2}{R_1}U_{vh2}\right] =$$

$$= \frac{R_4}{R_3}\left(1+2\cdot\frac{R_2}{R_1}\right)\left(U_{vh2}-U_{vh1}\right)$$

D.n.





$R_1 = R_2 = R_3 = R_4 = R_5 = R_6$

$i_2 = i_2$

$i_3 = i_5 + i_6$

$i_2 = i_4 + i_5 + i_6$

$i_2 = -\frac{U_{x1}}{R_2}$

$i_4 = \frac{U_{x1}}{R_4}$

$i_6 = \frac{U_{x2}}{R_6}$

$i_5 = \frac{U_{x2} - U_{izh}}{R_5}$

$$\Rightarrow -\frac{U_{x1}}{R_2} = \frac{U_{x1}}{R_4} + \frac{U_{x2}}{R_6} + \frac{U_{x2}}{R_5} - \frac{U_{izh}}{R_5}$$

$$\frac{U_{izh}}{R_5} = U_{x1}\left(\frac{1}{R_2}+\frac{1}{R_4}\right) + U_{x2}\left(\frac{1}{R_5}+\frac{1}{R_6}\right)$$

$$R_3\cdot i_3 = U_{x1} - U_{x2} \Rightarrow U_{x2} = U_{x1} - R_3(i_2+i_4) = U_{x1} - R_3\left(-\frac{U_{x1}}{R_2} - \frac{U_{x1}}{R_4}\right) =$$

$$i_3 + i_4 = i_2 \Rightarrow i_3 = i_2 - i_4 \qquad = U_{x1}\left(1+\frac{R_3}{R_2}+\frac{R_3}{R_4}\right)$$

$$\frac{U_{izh}}{R_5} = U_{x1}\left(\frac{1}{R_2}+\frac{1}{R_4}\right) + U_{x1}\left(1+\frac{R_3}{R_2}+\frac{R_3}{R_4}\right)\left(\frac{1}{R_5}+\frac{1}{R_6}\right) =$$

$$= U_{x1}\left(\frac{1}{R_2}+\frac{1}{R_4}+\frac{1}{R_5}+\frac{1}{R_6}+\frac{R_3}{R_2R_5}+\frac{R_3}{R_2R_6}+\frac{R_3}{R_4R_5}+\frac{R_3}{R_4R_6}\right) =$$

$$= U_{x1}\left( \qquad \right)$$

$$\frac{U_{vh}}{R_1} + \frac{U_{x1}}{R_2} = 0 \Rightarrow U_{x2} = -\frac{R_2}{R_1}U_{vh}$$

$$U_{izh} = -\frac{R_5\cdot R_2}{R_1}\cdot U_{vh}\left(\frac{1}{R_2}+\frac{1}{R_4}+\frac{1}{R_5}+\frac{1}{R_6}+R_3\left(\frac{1}{R_2R_5}+\frac{1}{R_2R_6}+\frac{1}{R_4R_6}+\frac{1}{R_5R_6}\right)\right) =$$

$$= -\cancel{R}\cdot U_{vh}\left(4\cdot\frac{1}{\cancel{R}}+4\cdot\frac{1}{\cancel{R}}\right) = -8\cdot U_{vh} \Rightarrow \underline{\underline{\frac{U_{izh}}{U_{vh}} = -8}}$$

## 2. način :

$u^+ = u^- = 0$

① $\frac{u_1 - u^-}{R} - \frac{u^- - u_{x1}}{R} = 0 \Rightarrow \frac{u_1}{R} + \frac{u_{x1}}{R} = 0$

② $\frac{u_x^- - u_{x1}}{R} - \frac{u_{x1}}{R} - \frac{u_{x1} - u_{x2}}{R} = 0 \Rightarrow -\frac{u_{x1}}{R} - \frac{u_{x1}}{R} - \frac{u_{x1}}{R} + \frac{u_{x2}}{R} = 0$

③ $\frac{u_{x1} - u_{x2}}{R} - \frac{u_{x2} - u_2}{R} - \frac{u_{x2}}{R} = 0 \Rightarrow \frac{u_{x1} - u_{x2}}{R} - \frac{u_{x2} - u_2}{R} - \frac{u_{x2}}{R} = 0$

$\Rightarrow \quad u_1 = -u_{x1} \Rightarrow u_{x1} = -u_1$

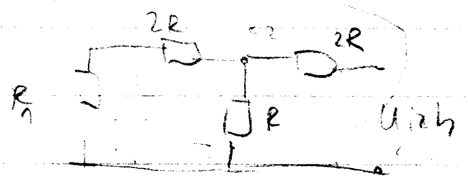
$\Rightarrow \quad -u_{x1} - u_{x1} - u_{x1} + u_{x2} = 0 \Rightarrow u_{x2} = 3u_{x1} = -3u_1$

$u_{x1} - u_{x2} - u_{x2} + u_2 - u_{x2} = 0 \Rightarrow -u_1 + 3u_1 + 3u_1 + u_2 + 3u_1 = 0$

$u_2 = -8u_1$

$A = -8$

$|A| = 8$



$u_{izh} = u_{vh} \cdot (1 + \frac{R_2}{R_1})$

$R_2 = 2R \| R \| 2R = (\frac{1}{2R} + \frac{1}{R})^{-1} \| 2R = (\frac{2R}{3}) \| 2R = (\frac{3}{2R} + \frac{1}{2R})^{-1}$

$10R$

$u_{izh} = u_{vh}(1 + 10)$

# DIGITALNA ELEKTRONIKA

UVOD:

Laboratorijska vaja : POLNI / POPOLNI SEŠTEVALNIK

zanimala nas bo implementacija (shematično)

videli bomo, da je shematičen način kar zamuden

↳ risanje vezja

Torej naša aritmetično - logična enota ALE bo opravljala le funkcijo seštevanja

VHDL ... programski jezik ... visokonivojski jezik ... na dosti krajši način bomo lahko naredili to, kar bomo delali celo 1. vajo

Obvladati moramo binaren zapis in linearno algebro !!

VDSL - modem (Iskratel)

Natisni si priročnik do naslednjič !

in ali ne

AND , OR , NOT vrata

NAND in NOR

| x | y | x and y |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 0 |
| 1 | 0 | 0 |
| 1 | 1 | 1 |

| x | y | x or y |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 0 |

| x | not x |
|---|---|
| 0 | 1 |
| 1 | 0 |

| x | y | x nand y |
|---|---|---|
| 0 | 0 | 1 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 0 |

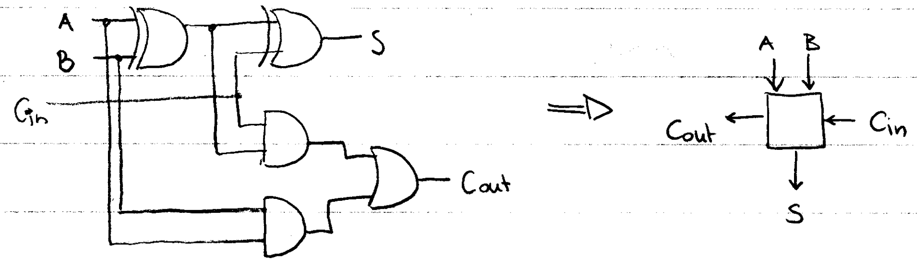
| x | y | x nor y |
|---|---|---|
| 0 | 0 | 1 |
| 0 | 1 | 0 |
| 1 | 0 | 0 |
| 1 | 1 | 1 |

čipi : CPLD in FPGA

Realizacija v C-MOS-u ... za realizacijo NAND vrat potrebujemo štiri tranzistorje, (CMOS) dva sta p-tipa, dva pa n-tipa

Popolni seštevalnik je vezje, ki ima dva vhode in prenos in izhod.

Realizacija na nivoju logičnih vrat:



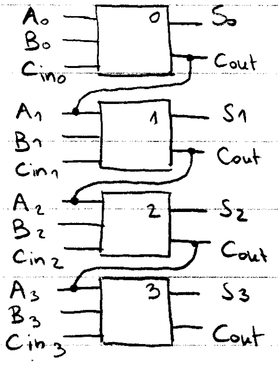
Imamo dve funkciji treh spremenljivk:

$$\overset{\text{Cout}}{C_{i+1}} = AB + A\overset{\text{Cin}}{C_i} + BC_i$$

$$S = A \oplus B \oplus C_i = A \oplus (B \oplus C_i)$$

TABELA

| A | B | $C_i$ | $C_{i+1}$ | S |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 1 | 0 | 1 |
| 0 | 1 | 0 | 0 | 1 |
| 0 | 1 | 1 | 1 | 0 |
| 1 | 0 | 0 | 0 | 1 |
| 1 | 0 | 1 | 1 | 0 |
| 1 | 1 | 0 | 1 | 0 |
| 1 | 1 | 1 | 1 | 1 |



Manjka vaja - popolni seštevalnik! Realizacija v shematic - okolju skripta !!!

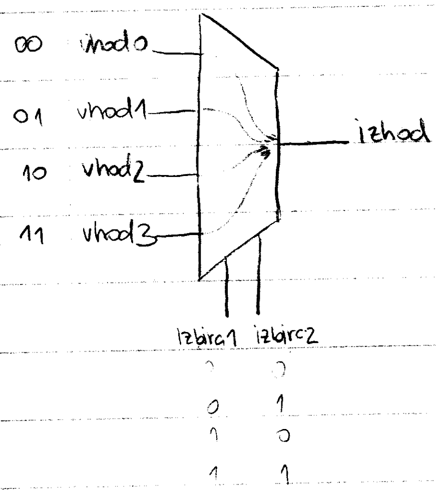
Logika

VHDL ukaz : izhod <= vhod0 when izbira = '0' else vhod1 ;

Sintakse se ne bomo naučili, ampak jo bomo skušali prebrati in glede na prejšnje primere rešiti nek nov primer.

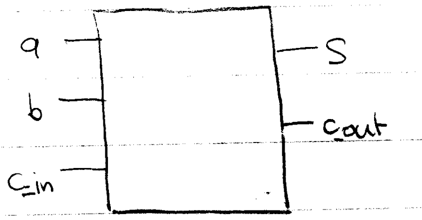
1. PRIMER (Kako se realizira MUX ?) - glej PDF-je

(new project, → add file ... odpri in poskusi razumeti !)



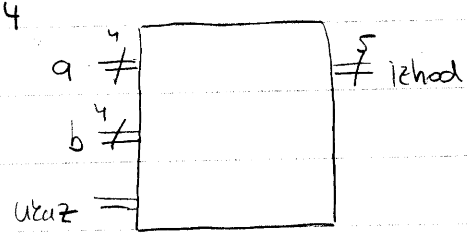
- Nariši vezje na nivoju vrat za ta primer :
  D.n.
- Kako bi to realizirali z VHDL ?
  (→ z vektorji si mnogo lažje predstavljamo signale ...)

Popolni seštevalnik



... To vezje imamo na računalniku, ga odberemo in realiziramo ... komentar :

ALE 4



Zakaj imamo na izhodu 5 bitov, če imamo 4-bitne vhode ? Odgovor je v seštevanju dveh štiribitnih (n-bitnih) števil ... rezultat je (n+1)-bitni. V našem primeru 5-bitni !

(• če pri negativnih številih spredaj dodajamo enke pa nič ne spremeni, če pri

www.stromar.si

Lab. vaja 13.5.09

① Dekodirnik: Navodila_VHDL_projekt1 → CPLD
↳ treba ga je nadgradit

* ucf datoteka

} 1.del
koraki implementacije

② Navodila_VHDL_projekt2 ... sistem na podlagi 1. dela

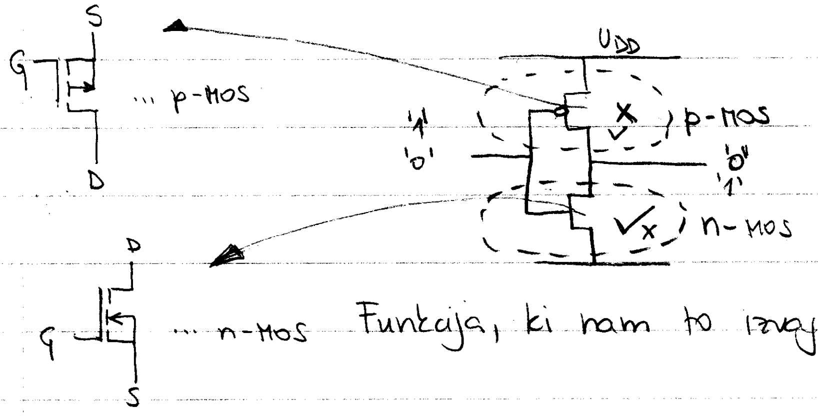
Razmisli o razliki med programiranjem mikroprocesorjev in VHDL!

pomeni komplementaren

# C-MOS TRANZISTOR

izpitna naloga: OSNOVNO DELOVANJE C-MOS TRANZISTORJA:

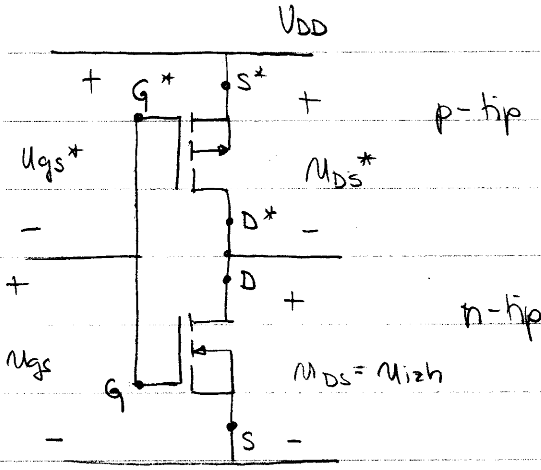
* C-MOS INVERTER IZGLEDA TAKOLE:

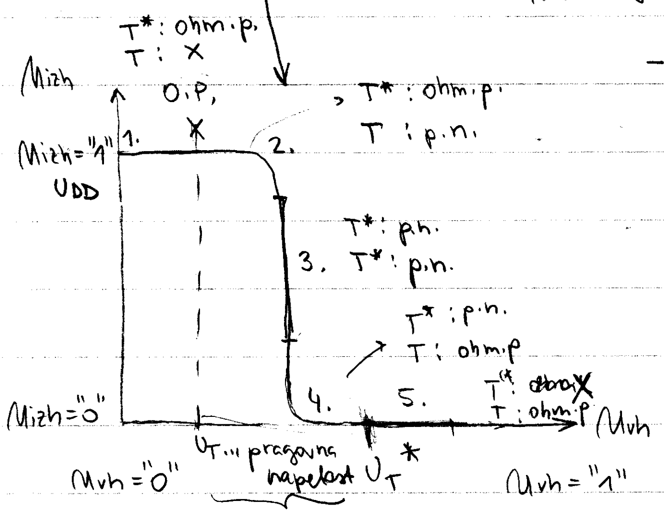


trazistorja sta komplementarna; ko je en odprt je drug zaprt

Funkcija, ki nam to izvaja je INVERTER

* Glej karakteristiko v knjig!





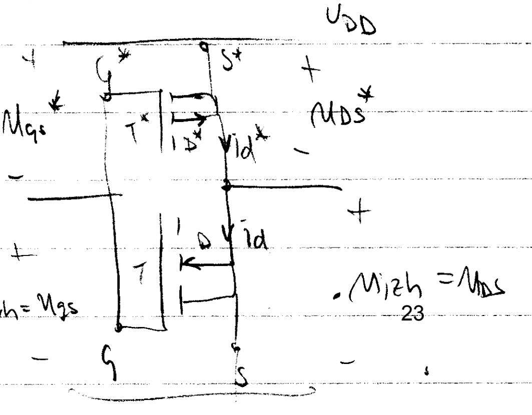
$u_{DS}^* = U_{DD} - u_{izh}$

$u_{izh} = U_{DD} - u_{DS}^*$

to je izpitno vprašanje!

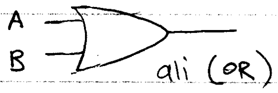
- glej knjigo

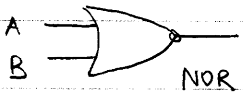
naš prehod je "hiter" in simetričen



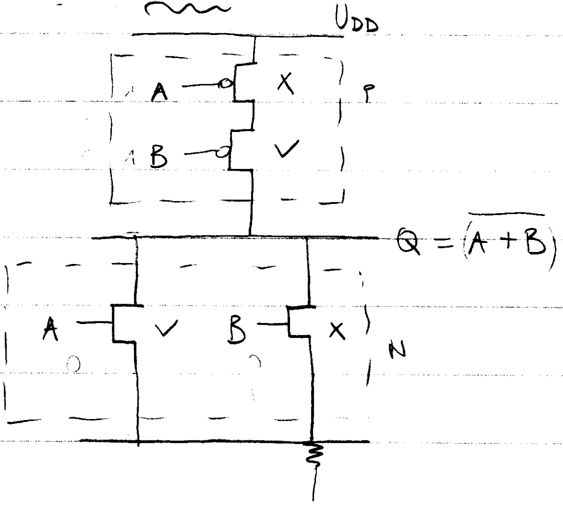
Tri Boolove operacije: in, ali, ne. Pri C-MOSu nas zanima kako realiziramo in in ali vrata.

| A | B | OR | NOR |
|---|---|---|---|
| 0 | 0 | 0 | 1 |
| 0 | 1 | 1 | 0 |
| 1 | 0 | 1 | 0 |
| 1 | 1 | 1 | 0 |





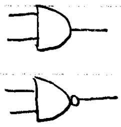
NOR

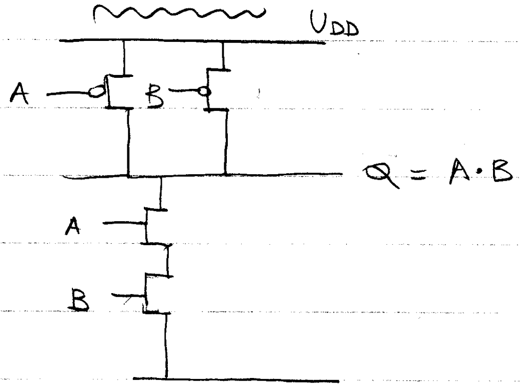


Vsaka aline (NOR) vrata potrebujeta: 4 tranzistorjev

NAND vrata

| A | B | NAND | AND |
|---|---|---|---|
| 0 | 0 | 1 | 0 |
| 0 | 1 | 1 | 0 |
| 1 | 0 | 1 | 0 |
| 1 | 1 | 0 | 1 |

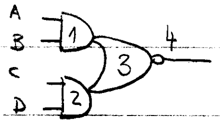


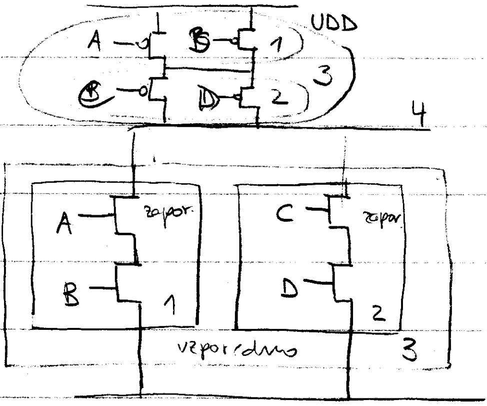


$\overline{Q} = A\,B =$

$Q = \overline{A} + \overline{B}$

Realizacija





Dvojna in vrata vezana z ali vrati:

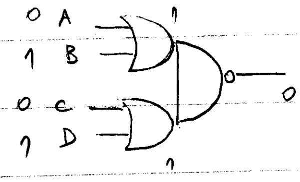
Kaj je na izhodu, če so na vhodu same enke ali same nule

↳ na izhodu je 0 → na izhodu je 1

Vse kar smo spodaj narisali zaporedno je zgoraj obratno!

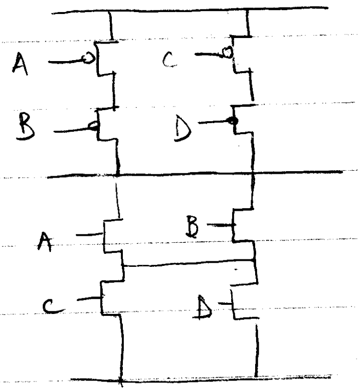
$\overline{Q} = A \cdot B + C \cdot D$

- Še ena realizacija za vajo:



Dvojna ali vrata vezana z ne vrati.
(narišemo najprej spodnji del in potem zgoraj vse komplementarno)

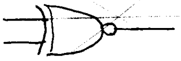
→ Moraš znat narisat realizacijo in preverit, če dela!



$\overline{Q} = (A+B)(C+D)$

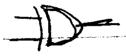
- Zanima nas še XOR funkcija in

XNOR:



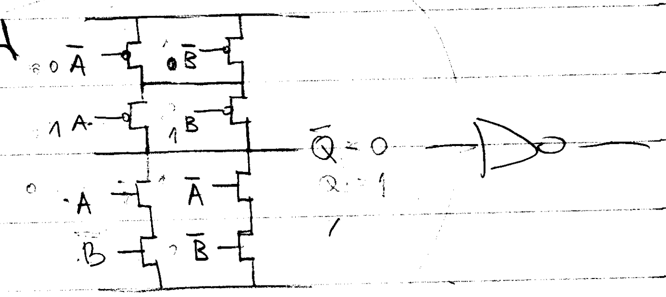
$\overline{Q} = \overline{xy + \overline{x}\overline{y}}$

XOR: $\overline{Q} = \overset{A}{x}\cdot\overline{\overset{B}{y}} + \overline{x}\cdot y$

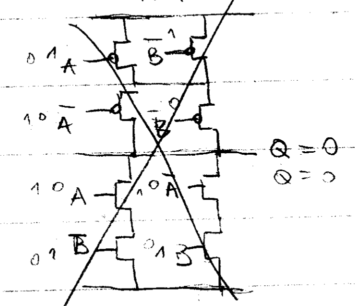


|  |  |  |  |  |  | Q | Q |
|---|---|---|---|---|---|---|---|
| x | y | $\overline{x}$ | $\overline{y}$ | $x\cdot\overline{y}$ | $\overline{x}\cdot y$ | XOR | XNOR |
| 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 |
| 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 |
| 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |

XOR



XOR



$\overline{Q} = xy + \overline{x}\overline{y}$

$\overline{xy + \overline{x}\overline{y}} = (\overline{x}+\overline{y})(x+y) =$

$Q = \overline{x}y + x\overline{y}$

$\overline{\overline{x}y + x\overline{y}} =$

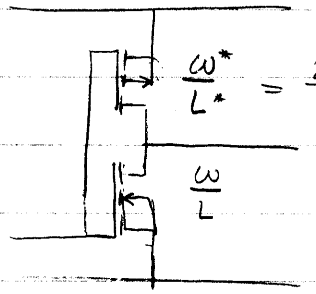
$f_{XOR} = \overline{f_{XNOR}} = \overline{xy + \overline{x}\overline{y}}$

Simetrična preklopna karakteristika : p-tip pišemo z zvezdico!

- Še neki si poglejmo : Dimenziranje tranzistorjev : dolžina kanala napram širini kanala :

Spomnimo se konstante : $k = \frac{\mu_n \cdot C_{ox} \cdot W}{2L}$ ; $k^* = \frac{\overset{\mu n/2}{\mu_p} \cdot C_{ox} \cdot W^*}{2L^*}$

$\mu_p \approx \overset{\text{do } 3\times}{2} \mu_n$ (mobilnost protonov je 2× mobilnost elektronov)



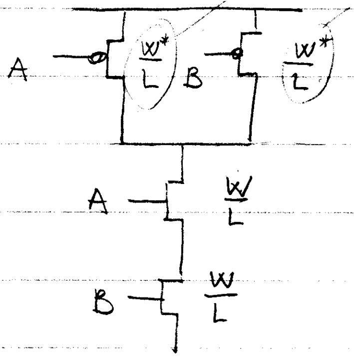
$L = L^*$

$W = \frac{W^*}{2}$

$W^* = 2W$

PRIMER :

to smo ugotavljali

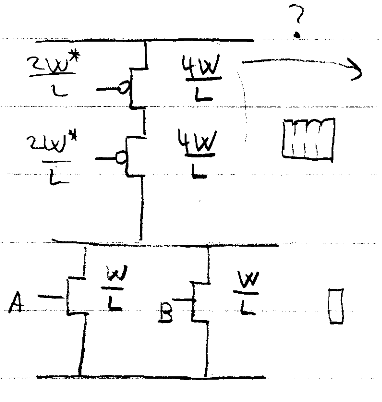


$= \frac{W^*}{L} = \frac{2W}{L}$

$\|$

$\frac{2W}{L}$

PRIMER :



faktor 2 pride zaradi manjše mobilnosti

In še faktor 2 zaradi dolžine kanala

Izpit :

- prenosne karakteristika nekega vezja
- Bodejev diagram
- polvalni usmerniki
- VHDL (A, B, C, D) - skripta na netu

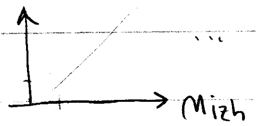
## ZADNJE VAJE – Povzetek celega leta

μp

- Kakšna je razlika med mikroprocesorji in FPGA-ji?
- μp in FPGA-ji realizirajo pretvorbo signale in analognega v digitalnega
- Zmogljivejši FPGA-ji imajo znotraj sebe še en μp.... ?
- Spoznali smo VHDL za programiranje čipov ?

① Operacijski ojačevalnik

– časovni (uizh)



... to je prenosna karakteristika

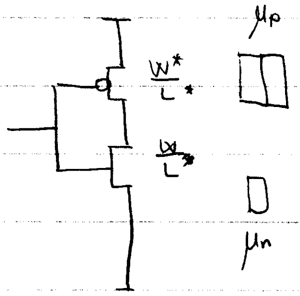
② Instrumentacijski ojačevalnik – polvalni usmernik

③ Bodejev diagram (dal bo neko konstulacijo, pa bo treba ven razbrat izraz npr. $z_2/z_1$ in pol narisat)

④ VHDL – osnovni gradniki

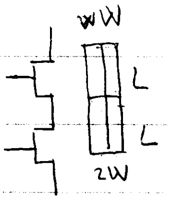
⑤ C-MOS – cela teorija iz knjige!!! mormo znat povedat neki o delovanju poudarek na C-mos invertorju
- realizacija funkcije na c-mosu
- W/L

C - MOS

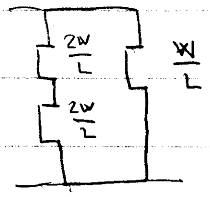


- manjša mobilnost

pri isti dolžini $L=L^*$
je $W^* = 2W$

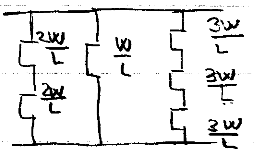


pri serijski vezavi rabim 2× širši



zaporedna vezava

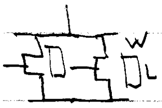
n-tip



to je zdej najslabša pot!

to pomeni tri vhodna vrata

n-tip

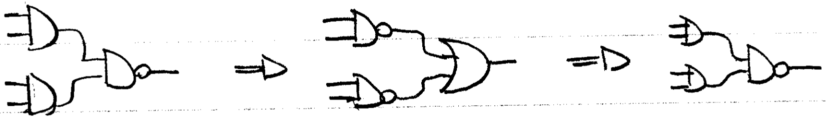


vzporedna vezava - nimamo teh težav

~ gledam najslabši primer (če imam več poti gledam tisto, ker rabim največ) ... gledam najdaljšo pot (največ L)

To je koncept, naprej pa poglej doma - ker bo to na izpitu

Kako iz logičnih vrat sestaviš tranzistorsko vezavo, Znamo sestavit poljubno kombinacijo nenegiranih vrat, ki so na koncu povezane z negiranimi vrati... treba je znat narest tudi obratno



Glej deMorgana!