ELE 1
8.1.11

1. FIZIKA RADA TRANZISTORA

IZLAZNE KARAKT. NPN SU NA SLICI U TOČKI

C: $\gamma = 0,99$ $\qquad$ $U_T = 25 mV$

$B^+ = 0,995$ $\qquad$ $I_{CBO} \rightarrow$ ZANEMARIN

(NAP)

$-3 nA$

A B $-2 nA$

C $-1 nA \; I_{UL}$

ZASIĆENJ.

$U_{IZ} (U_{CB})$
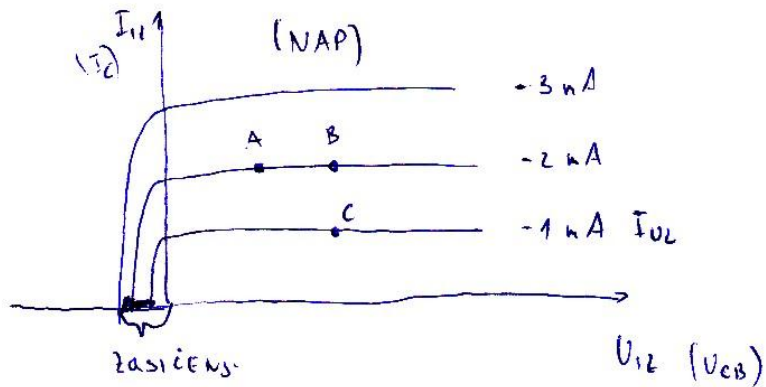
1a) odrediti spoj za koji vrijedi ova karakteristika i obrazložiti

za npn $I_E < 0$ $\quad I_B, I_C > 0$

$I_{UL} < 0$ $\quad I_{UL} = I_E \Rightarrow$ SPOJ ZAJEDNIČKE BAZE
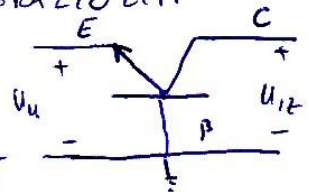
ULAZ = E
IZLAZ = C
ZAJD = B

NAP $\rightarrow$ SPOJ B-E $\Rightarrow$ PROPUSNO
$\qquad$ B-C $\Rightarrow$ ZAPORNO

ZASIĆENJE $\Rightarrow$ SPO· B-E $\rightarrow$ PROPUSNO
$\qquad$ B-C $\rightarrow$ PROPUSNO

$U_{CB} = 0 V$ granica zasićenja

EIEI

8.1.11

1 b) ZA TOČKU C ODREDITI SVE KOMPONENTE STRUJA

STRUJE VANJSKIH PRIKLJUČAKA

$\gamma = 0,99$ $\beta^* = 0,995$ $I_E = U_{0L} = -1 mA$ (iz karakteristike)

$$\gamma = \frac{I_{nE}}{I_{nE} + I_{pE}}$$

$$= \frac{I_{nE}}{-I_E}$$

$I_{nE} = -I_E \cdot \gamma$

$= -(-1) \cdot 0,99$

$= 0,99 \, mA$

$-I_E = I_{nE} + I_{pE}$
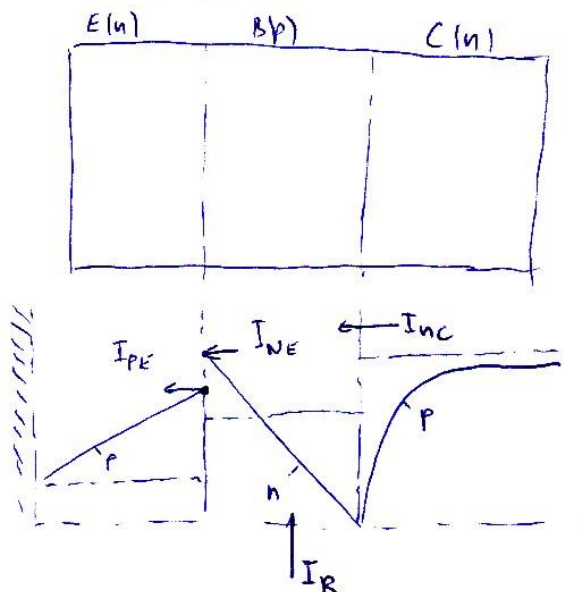
$I_{pE} = -I_{nE} - I_E = -(-1) - 0,99 = 0,01 \, mA = 10 \, \mu A$

$I_R = I_{nE} - I_{nC} \; \div \; I_{nE} - \underbrace{\beta^* I_{nE}}_{I_{nC}} = \dots = 4,95 \, \mu A$

$\beta^* = \frac{I_{nC}}{I_{nE}}$

→ PAZITI NA DECIMALE 5-6 DECIMALA (4 min)

$I_{nC} = \beta^* \cdot I_{nE} = 0,995 \cdot 0,99 = 0,98505 \, mA = I_C$

$I_E + I_C + I_B = 0$

$I_B = -I_E - I_C = -(-1) - 0,98505 = 14,95 \, \mu A$

$I_B = I_{pE} + I_R = 10 + 4,95 = 14,95 \, \mu A$ (ALTERNATIVNI NAČIN PREKO KOMPONENTI STRUJE)
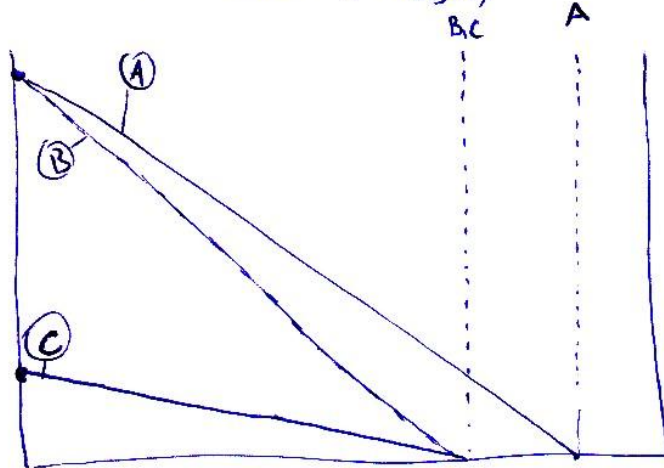
EIG 3

1c) NA ISTOJ SLICI KVALITATIVN NACRTAI   8.1.11

RASPODJELU MANJINSKIH NOSILACA U BAZI

ZA RADNE TOČKE (A, B, C):

A, B, C   SU U NAP $\Rightarrow$ PROPUSNO POLARI   B — E
                        ZAPORNO   B — C

STRUJA C IMA MANJU ILN OD I_A $I_{c}(c) < I_{c}(A) < I_{c}(B)$

NAPON $U_{CB}(B) = U_{CB}(C) > U_{CB}(A)$

gradijent (C) $<$ gradijent (A) $<$ gradijent (B)

$U_{BE}(A) \doteq U_{BE}(B) > U_{BE}(C)$

$\quad\quad\hookrightarrow$ RUBNE KONCENTRACYE PRIDLIŽNO =

$n_{BO}(A) = n_{BO}(B) > n_{BO}(C)$

ElE4
8.1.11

2 BIPOLARNI SI TRAZNI IMA KAVRCAM NABOJ MANJINSKI ELEKTRONA URALI $Q_{nB} = 4pAs$ UNEKOJ RADNOJ TOČ U NAP NAPON $U_{BE} = 0,55V$ A EFIKASNOST EMIT $\gamma = 0,9925$

EFEKTIVNA ŠIRINA BAZE $W_B = 1\mu m = 10^{-4}cm$

POKRETLJIVOST MANJINSK NOSIOCA URM $\mu_{nB} = 600\ cm^2/V_s$

$\tau_{nB} = 0,6\ \mu s$ (VRIJEME ŽIVOTA NOSIOI POVRŠINA SPOJA $S = 1mm^2$
$= 10^{-2}cm^2$

a) ODR. KONCENTRACIJA DOPANADA (PRIMJESA) U BAZI

→ U BAZI ELEKTRONI MANJINSK P TIP ⟹ $\boxed{E(n)\ |B(p)|\ C(n)}$

$$Q_{nB} = \frac{n_{BO} \cdot W_B}{2} \cdot q \cdot S$$

$$n_{BO} = \frac{2Q_{nB}}{q \cdot S \cdot W_B} = \dots = 5 \cdot 10^{13}\ cm^{-3}$$
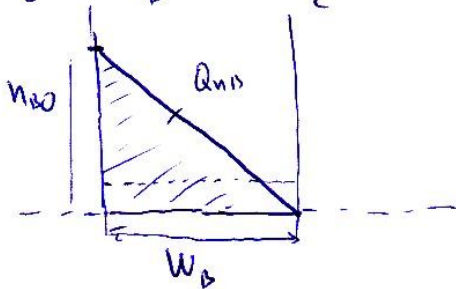
$$n_{BO} = n_{OB} \cdot \left(exp\frac{U_{BE}}{U_T}\right) \qquad n_{OD} = n_{OO} \cdot exp\left(\frac{-U_{BE}}{U_T}\right) = 1,395 \cdot 10^4\ cm^{-3}$$

$$n_{OB} = \frac{n_i^2}{P_{OB}} = \frac{n_i^2}{N_{AB}} \qquad N_{AB} = \frac{n_i^2}{n_{OD}} = \frac{(1,45 \cdot 10^{10})^2}{1,395 \cdot 10^4} = 1,51 \cdot 10^{16}$$

ElES
8.1.11

2b) IZR SVE KOMPONENTE STRUJA TE I_C, I_B, I_E

ODREDITE POJAČAL α, β I VRYEME PROLETA KROZ BAZU (t_{tr})

1. NAČIN $I_{ne} \rightarrow$ IZ RASPODJELE NOSIOCA

$$I_{ne} = q \cdot S \cdot D_{nB} \frac{\partial n}{\partial s} = q \cdot S \cdot \mu_0 V_T \frac{n_{B0}}{W_B}$$

$$= 1,6 \cdot 10^{-19} \cdot 10^{-2} \cdot 600 \cdot 25 \cdot 10^{-3} \frac{5 \cdot 10^{15}}{10^{-4}} = \ldots = \underline{12\ mA}$$

2 NAČIN : PREKO NAKUPLANOG NABOJA

$$I_{ne} = \underbrace{q \cdot S \cdot D_{nB} \frac{n_{B0}}{W_B}}_{Q_{nB}} \cdot \underbrace{\frac{W_B}{W_D} \cdot \frac{2}{2}}_{2D_{nB}/W_B^2} = Q_{nB} \cdot \frac{2D_{nB}}{W_B^2} = Q_{nB} \frac{1}{t_{TR}}$$

$$= Q_{nB} \frac{2\mu V_T}{W_B^2} = 4 \cdot 10^{-12} \frac{2 \cdot 600 \cdot 25 \cdot 10^{-3}}{(10^{-4})^2} = \ldots = \underline{12\ mA}$$

$$t_{tr} = \frac{W_B^2}{2 D_{nB}} = \frac{10^{-4}}{2 \cdot 600 \cdot 25 \cdot 10^{-3}} = \underline{0,33\ nS}$$

$$I_B = \frac{Q_{nB}}{\tau_{nB}} = \frac{4 \cdot 10^{-12}}{0,6 \cdot 10^{-6}} = \underline{6,67\ \mu A}$$

$$\gamma = \frac{I_{ne}}{I_{ne} + I_{pE}} = \frac{1}{1 + \frac{I_{pE}}{I_{ne}}} \qquad \frac{1}{\gamma} = 1 + \frac{I_{pE}}{I_{nE}}$$

$$I_{pE} = \left(\frac{1}{\gamma} - 1\right) I_{ne} = \left(\frac{1}{0,9925} - 1\right) \cdot 12\ nA = \underline{90,7\ \mu A}$$

ELE 6
8.1.11

$$I_E = -\left(I_{nE} + I_{pE}\right) = -12,091 \text{ mA}$$

$$I_E < 0 \quad \text{za} \quad npn \quad \text{tranzistore} \quad !!!$$

$$I_{nc} = I_{nE} - I_R = 12 \cdot 10^{-3} - 6{,}67 \cdot 10^{-6} = 11{,}9933 \text{ mA} = I_C$$

$$I_B = -I_C - I_E = -11{,}9933 - (-12{,}091) = 97{,}3 \text{ μA}$$

2 NAČIN

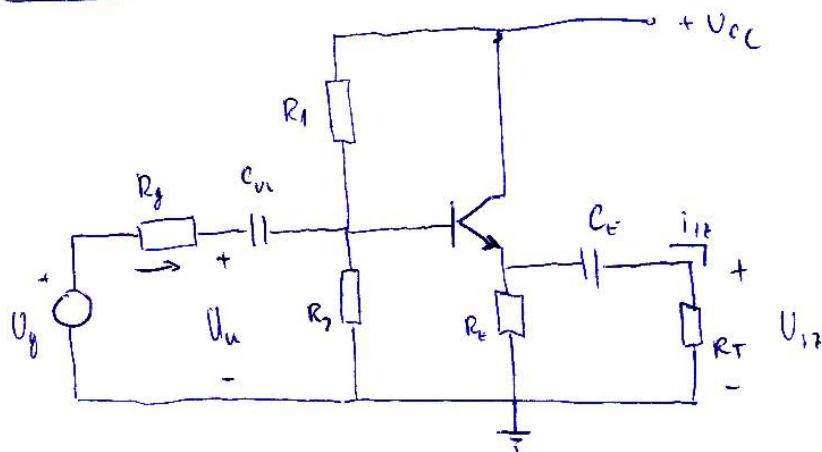$$I_D = I_R + B_{BE} = (6{,}67 \cdot 90{,}7) = 97{,}37 \text{ μA}$$

POJAČ

$$\alpha = \frac{I_C}{-I_E} = \frac{11{,}9933}{-(-12{,}091)} = 0{,}9919 \quad \text{(min 4 dec)}!$$

$$\beta = \frac{\alpha}{1-\alpha} \quad \text{ili} \quad \frac{I_C}{I_B} = \frac{11{,}9933}{0{,}0974} = 123 \quad \left(\text{na cijeli broj jer je već veličin 100}\right)$$

2 NAČ. POJAČ

$$\alpha = \gamma \cdot \beta^* \qquad \beta = \frac{\alpha}{1-\alpha}$$

POJAČALA

ELE 7
8.1.11

$U_{cc} = 12 V$

$R_1 = 100 k$

$R_2 = 150 k$

$R_T = 3,3 k$

$R_E = 4,7 k$

$R_G = 500 \Omega$

$\beta = h_{fe} = 200$

$U_\gamma = 0,7 V$

$U_T = 25 mV$

$A_{V_1}, A_{T_1}, A_{V G_1}, R_{ul}, R_{iz}$

SZC

STATIKA

- ODSPOJIMO GRANE SA ─╢─

U_{BB}, R_D

(PO THEV.)
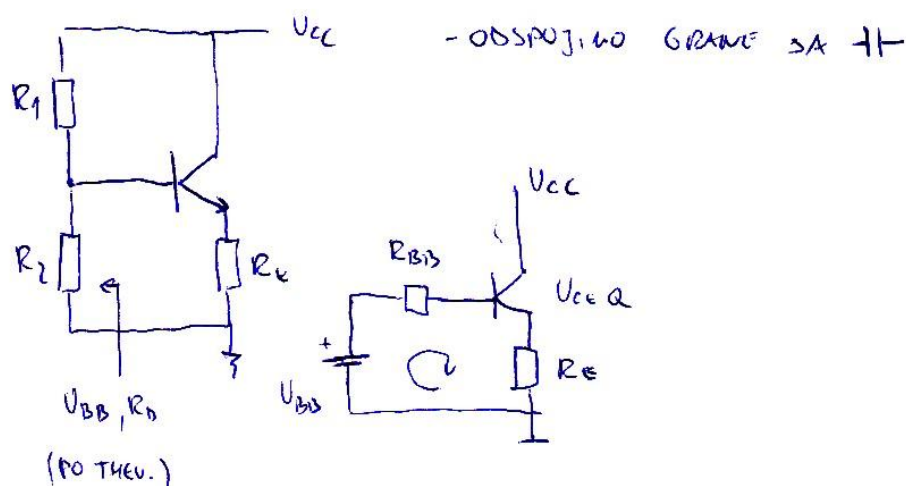
$$I_{BQ} R_B + U_{BEQ} + (1+\beta) I_{BQ} \cdot R_E - U_{BB} = 0$$

$$I_{BQ} = \frac{U_{BB} - U_{BEQ}}{R_D + (1+\beta) \cdot R_E} = \ldots = 6,47 \, \mu A$$

$$R_D = R_1 \| R_2 = 60 \, k\Omega$$

$$U_{BB} = U_{cc} \frac{R_2}{R_1 + R_2} = 7,2 \, V$$

$$I_{CQ} = \beta \cdot I_{BQ} = 200 \cdot 6,47 \mu A = 1,294 \, mA$$

$$\overline{U_{CEQ}} = U_{cc} - I_{EQ} \cdot R_E \doteq U_{cc} - I_{CQ} \cdot R_E = 5,92 \, V \qquad U_{CEQ} > U_{BEQ}$$

$$\hookrightarrow NAP$$

DIN. PARAMET.

ELE 8
8.1.11

$$r_{BE} = \frac{V_T}{I_{BEQ}} = \frac{25 \cdot 10^{-3}}{6,67 \cdot 10^{-6}} = 3,864 \ k\Omega$$

$$g_m = \frac{I_{CQ}}{V_T} = \frac{1,294 \ mA}{0,025 \ V} = 51,76 \ \frac{mA}{V}$$

NADOMJESNI SKLOP: "GENERIČKI"

ZADANO

ULAZ — B

IZLAZ — E
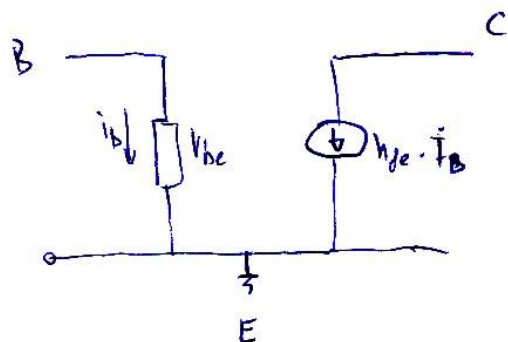
ZAJEDN. — C

DINAM. NADOMJESNA SHEMA: - KRATKI SPAJNO ⊣⊢
   - Ucc na masu

$R_B = R_1 \| R_2$

ELES
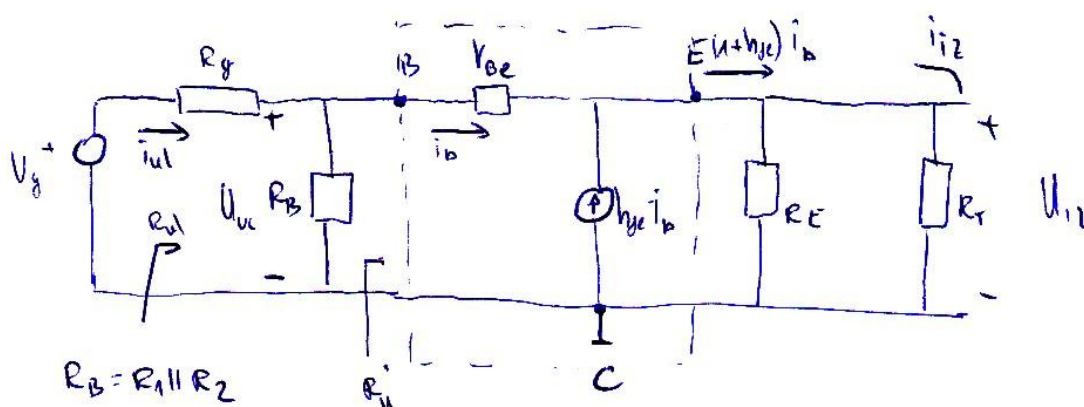
8.1.11

$$A_V = \frac{U_{iz}}{U_{ul}} = \frac{(1+h_{fe})\,i_b \cdot (R_E \| R_T)}{i_b \cdot r_{BE} + (1+h_{fe})\,i_b \cdot (R_E \| R_T)}$$

(znati izvest)

$$= \dots = \frac{201 \cdot 1{,}939}{3{,}864 + 201 \cdot 1{,}939} = \dots = \underline{\underline{0{,}99}}$$

$A_V < 1 \; ; \; A_V > 0$

$- U_{ul} \; i \; U_{iz} \Rightarrow$ u fazi

$\Rightarrow$ emitevsko slijedilo

$$R_{ul} = \left\{ \frac{U_{ul}}{I_{ul}} \right\} = R_B \| R_{ul}'$$

$$R_{ul}' = \frac{U_{ul}'}{i_{ul}'} = \frac{i_B \cdot r_{be} + (1+h_{fe})\,i_b \,(R_E \| R_T)}{i_B} = \dots = 394 \, k\Omega$$

$$\underline{R_{ul} = R_B \| R_{ul}' = \dots = \underline{\underline{52 \, k\Omega}}}$$ R_{ul} je velik

$$A_I = \frac{i_{iz}}{i_{ul}} = \frac{\frac{U_{iz}}{R_T}}{\frac{U_{ul}}{R_u}} = \underbrace{\left(\frac{U_{iz}}{U_{ul}}\right)}_{A_V} \frac{R_u}{R_T} = A_V \cdot \frac{R_u}{R_T} = \underline{\underline{15{,}6}}$$ $A_I > 0$
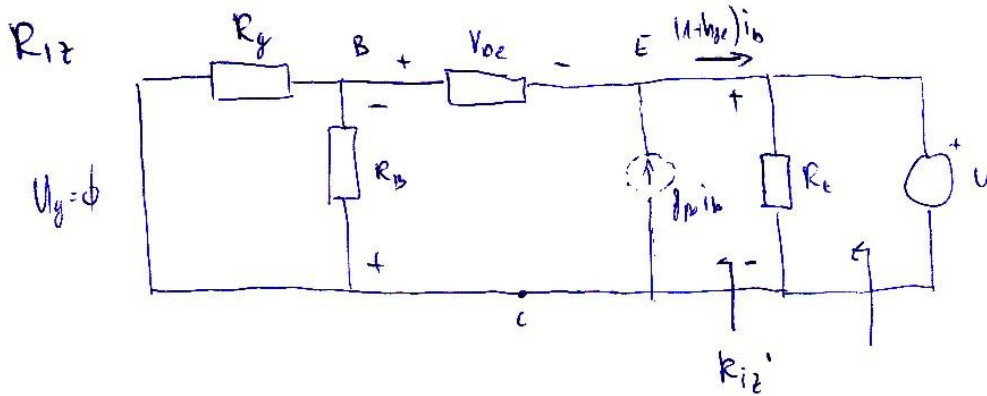
$-$ može se postić veliko strujno pojačanje

$-$ može se postić pojačanje snage szc

$$A_{VG} = \frac{U_{iz}}{U_G} = \frac{U_{iz}}{U_{ul}} \frac{U_{ul}}{U_G} = A_V \cdot \frac{U_{ul}}{U_G} = A_V \frac{R_u}{R_u + R_g} = \underline{\underline{0{,}98}}$$ $A_V \approx A_{VG}$

velik ulazn. otpor

R_{iz}

EE 10
8.1.11

$$R_{iz} = R_E \| R_{iz}'$$

$$R_{iz}' = \frac{U''}{i''} = \frac{-i_b \cdot V_{DE} - i_b \, R_g \| R_B}{-(1+h_{fe}) i_b} = \frac{V_b + R_G \| R_B}{1 + h_{fe}} = \dots = 21,7 \, \Omega$$
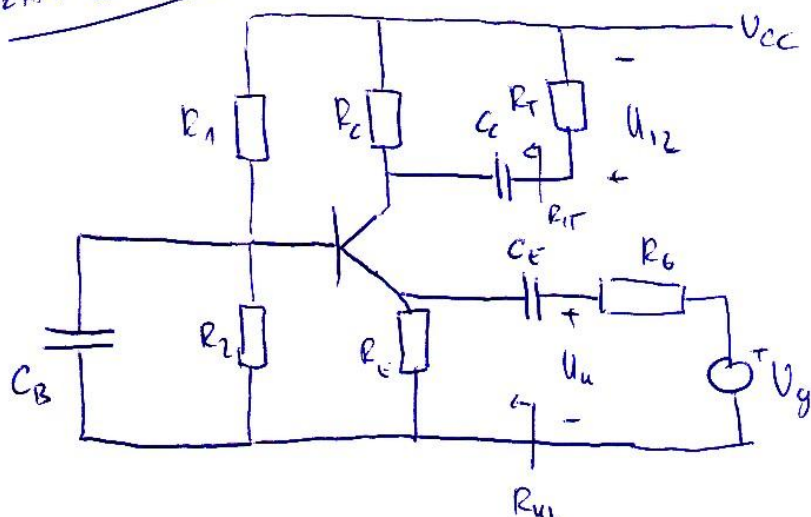
→ OTPOR IZ KRUGA BAZE SE U KRUG EMETTIRE SE
PRESLIKAVA $(1+h_{fe})$ PUTA MANJI

$$\underline{R_{iz} = R_E \| R_{iz}' = 21,6 \, \Omega} \qquad \rightarrow \underline{\text{mali izlazi otpor}}$$

U EMITERU SE VIDI MALI OTPOR

DOBRO NAPONSKI POJAČAO JER SE MALO GUBI ALI JE STRUJNO
POJAČANJE VELIKO.

ZAU. 2 26.1.09

etc 11
8.1.11

$V_{cc} = 10$

$R_g = 500$

$R_1 = 82 \, k\Omega$

$R_2 = 22 \, k\Omega$

$R_e = 4,7 \, k\Omega$

$B = h_{dc} = 150$
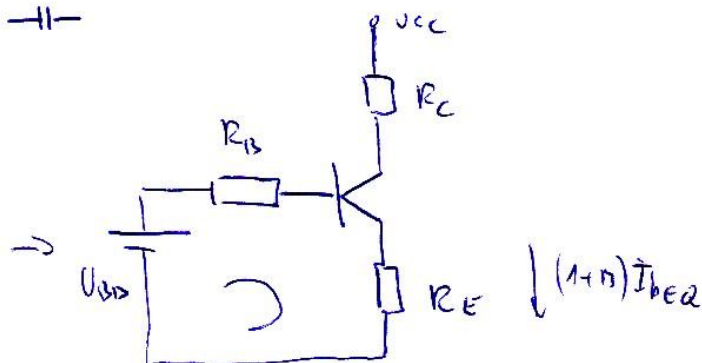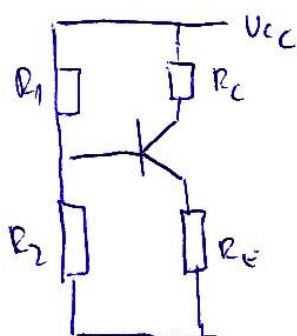
$U_t = 0,7 \, V$

$U_T = 25 \, mV$

STATIKA

- ODSPOJIMO SVE ZA —||—

$U_{BB} = U_{cc} \dfrac{R_2}{R_1 + R_2} = \cdots = 2,12 \, V$ $R_B = R_1 \| R_2 = 17,35 \, k\Omega$

$$I_{BQ} \cdot R_B + U_{BEQ} + (1+B) I_{BEQ} \cdot R_E - U_{BB} = 0$$

$$I_{BQ} = \frac{U_{BB} - U_{BQ}}{R_B + (1+B) R_E} = 4,06 \, \mu A$$
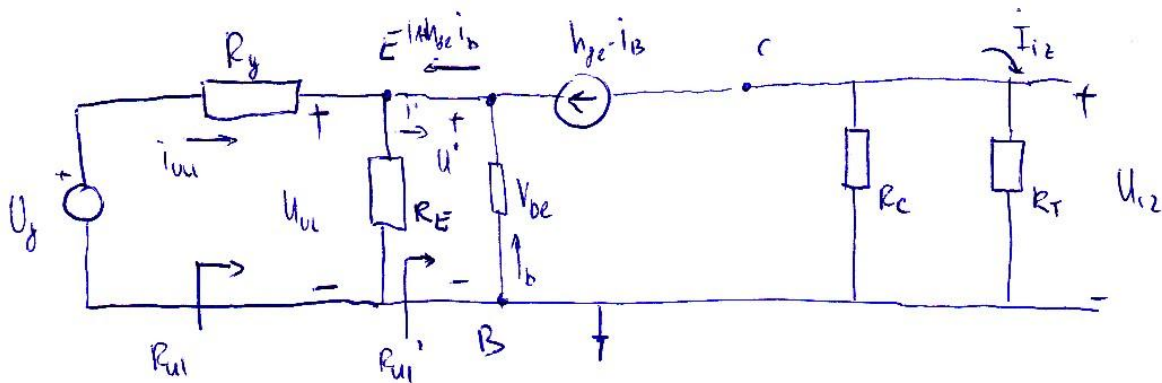
$$I_{CQ} = B \, I_{BQ} = 0,609 \, mA$$

EIE 12

8.1.11

$$U_{CQ} \approx U_{CC} - I_{CQ}(R_C + R_E) = 5,8V \qquad > U_{BEQ} \Rightarrow NAP \checkmark$$

DINAMIČKI PAR

$$V_{be} = \frac{U_T}{I_{BQ}} = 6,16 \, k\Omega$$

$$g_m = \frac{I_{CQ}}{U_T} = 24,36 \, mA/V \checkmark \qquad\qquad SZB$$

$$A_V = \frac{u_{i2}}{u_{u1}} = \frac{-h_{je} \cdot i_B \cdot (R_C \| R_T)}{-i_b \cdot V_{be}} = \frac{h_{je}(R_C \| R_T)}{V_{be}} = \frac{150(4,7 \| 4,7)}{6,16} = 57,2 \quad A_V > 0$$

→ u1 i i2 su u FAZI

$$R_{u1} = R_E \| R_{u1}'$$

$$R_{u1}' = \frac{u'}{i'} = \frac{-i_b \cdot V_{be}}{-(1+h_{je})i_b} = \frac{V_{be}}{1+h_{je}} = 41\Omega$$

OTPOR IZ KRUGA BAZE U EMITER $(1+h_{je})$ PUTA MANJI

RED VELIČINE 10 TAK OMA $(10-20\,\Omega)$

$$R_{u1} = R_E \| R_{u1}' = \underline{40\Omega} \qquad R_{u1} \text{ je mali}$$
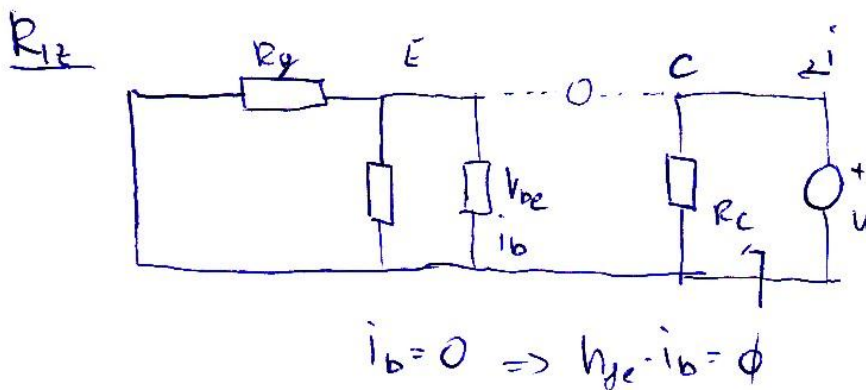
– U EMITER VIDIMO MALI OTPOR

$$A_{vg} = \frac{U_{i2}}{U_g} = \frac{U_{i2}}{U_{uc}} \cdot \frac{U_u}{U_g} = A_v \frac{R_{ul}}{R_{uv} + R_g} = 4,24$$

ELE 15

8.1.11
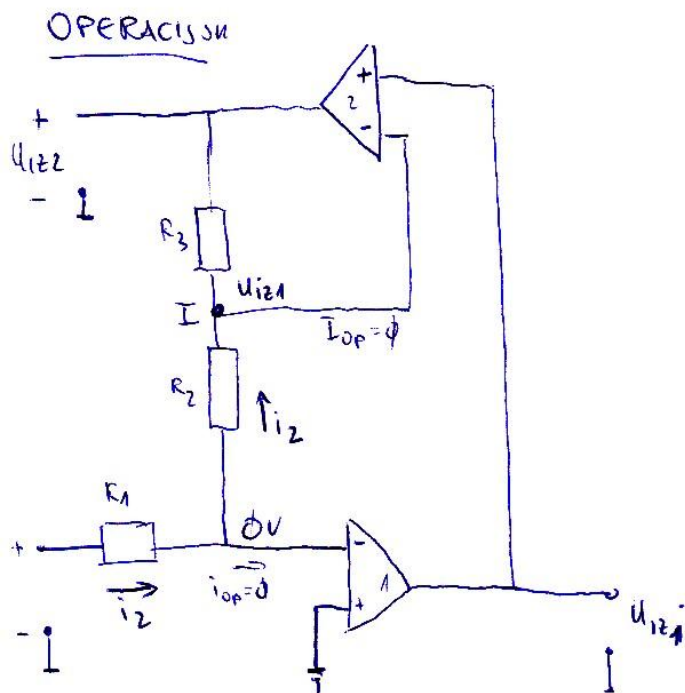
R_{ul} je mali PA JE $A_v \neq A_{uc}$ jako RAZLIČIT

$$A_I = \frac{i_{i2}}{i_{ul}} = \frac{\frac{U_{i2}}{R_t}}{\frac{U_{uc}}{R_u}} = A \frac{R_{ul}}{R_t} = 0,49 \qquad A_i < 1 \quad A_I > 0$$

R_{iz}

$i_b = 0 \Rightarrow h_{je} \cdot i_b = \phi$

$$R_{i2} = \frac{V}{I} = \underline{\underline{R_c}} \qquad \text{KADA JE IZLAZ NA C TADA JE}$$

$$R_{i2} = R_c$$

OPERACIJSKI

U_{iz2} + − I

R_3

u_{iz1}

I

$I_{op} = \phi$

R_2

$\uparrow i_2$

R_1

$+$ 0V $I_{op} = 0$

$\xrightarrow{i_2}$

$-$

U_{iz1}

ELE 14

8.1.11

- IZVESTI IZRAZ U_{iz1} i U_{iz2}

- KOLIKA JE VR. R_1 AKO SU

  $U_{iz2} = 7,5 V$

  $U_{ul} = -0,275 V$

  $R_2 = R_3 = 20 k\Omega$

- IDEALNO OP

① $R_{ul} = \infty \rightarrow I_{op} = \phi$

② $A_v = \infty \rightarrow U_{uz} = A_v U_{ul}$

   $U_+ + V_- = \dfrac{U_{uz}}{A_v} = \phi$

   $U_+ = U_-$ ⇒ PRIVIDNI KRATKI SPOJ

   ULAZNIH STEZALJKI

③ $R_{iz} = \phi$

NE PIŠEMO JED.Ž. ZA IZLAZNI ČVOR

$i_1 = i_2$

$$\frac{U_{ul} - \phi}{R_1} = \frac{\phi - U_{iz1}}{R_2}$$

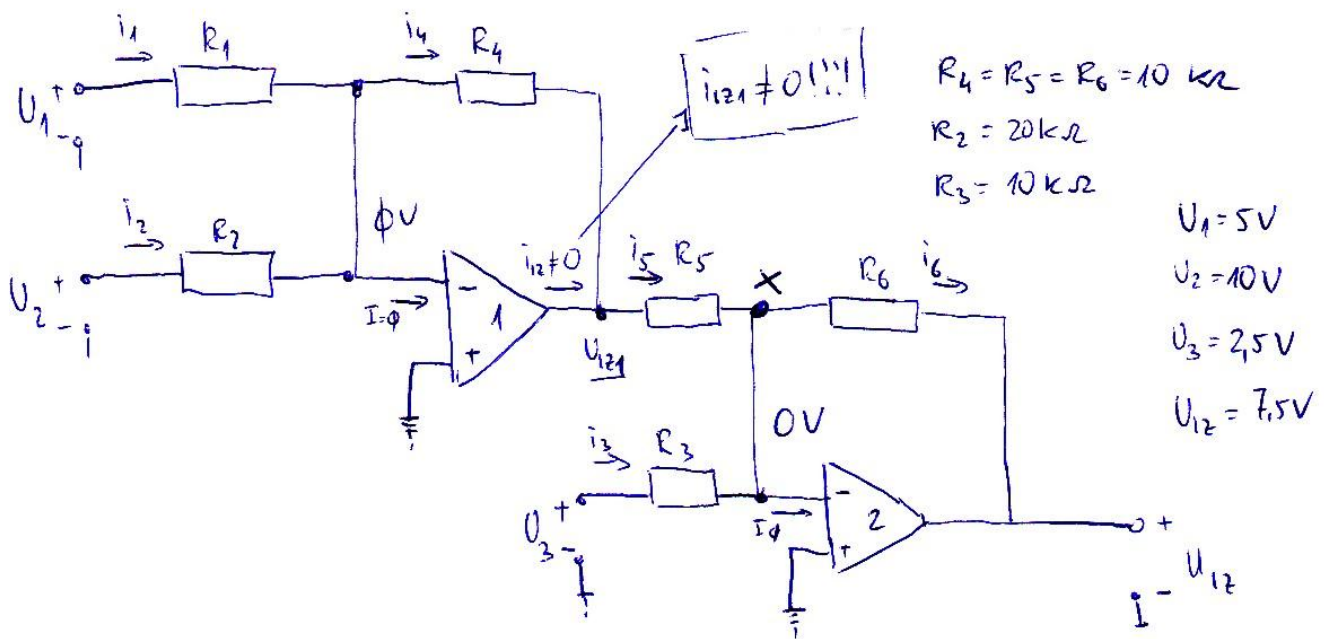$$\boxed{U_{iz1} = -\frac{R_2}{R_1} \cdot U_{ul}}$$

$(I) \quad i_2 = i_3$

$$\frac{0 - U_{iz1}}{R_2} = \frac{U_{iz1} - U_{iz2}}{R_3} \Rightarrow U_{iz2} = U_{iz1}\left(1 + \frac{R_3}{R_2}\right) = -\frac{R_2}{R_1}\left(1 + \frac{R_3}{R_2}\right) U_{ul}$$

$$U_{ul2} = -\frac{R_2}{R_1}\left(1 + \frac{R_3}{R_2}\right)U_{ul} \Rightarrow R_1 = -R_2\left(1 + \frac{R_3}{R_2}\right)\frac{U_{ul}}{U_{iz2}} = \underline{\underline{1,2 \, k\Omega}}$$

28.1.2007. Z.I

EK 15

8.1.11

$$i_{iz1} \neq 0 !!!$$

$$R_4 = R_5 = R_6 = 10\,k\Omega$$
$$R_2 = 20\,k\Omega$$
$$R_3 = 10\,k\Omega$$

$$U_1 = 5V$$
$$U_2 = 10V$$
$$U_3 = 2,5V$$
$$U_{12} = 7,5V$$

-I koji ulazi u OP $= \phi$

$\Rightarrow$ VIRTUALNI KRATKI SPOJ

JED. ZA U_{iz1}

$$i_1 + i_2 = i_4$$

$$\frac{U_1 - 0}{R_1} + \frac{U_2 - 0}{R_2} = \frac{0 - U_{iz1}}{R_4}$$

$$\boxed{U_{iz1} = -\frac{R_4}{R_1} \cdot U_1 - \frac{R_4}{R_2} U_2}$$

$i_4 \neq i_5$ jer je $i_{12} \neq \phi$

$\rightarrow$ ne pišemo str. jed. za izlazni čvor

x

$$i_5 + i_3 = i_6$$

$$\frac{U_{iz1} - 0}{R_5} + \frac{U_3 - 0}{R_3} = \frac{0 - U_{12}}{R_6}$$

$$U_{12} = -\frac{R_6}{R_5} U_{iz1} - \frac{R_6}{R_3} U_3 \quad (\text{uvrstimo } U_{iz1})$$

$$U_{12} = -\frac{R_6}{R_5}\left[\left(-\frac{R_4}{R_1}\right)U_1 - \frac{R_4}{R_2} U_2\right] - \frac{R_6}{R_3} U_3$$

ELE 16

8.1.11

$$U_{17} = \frac{R_6 \cdot R_4}{R_5} \left[\frac{U_1}{R_1} + \frac{U_2}{R_2} \right] - \frac{R_6}{R_3} U_3$$

$$\vdots$$

$$\Rightarrow R_1 = \frac{U_1}{\dfrac{R_5}{R_6 \cdot R_4} \left(U_{17} + \dfrac{R_6}{R_3} U_3 \right) - \dfrac{U_2}{R_2}} = \dots = 10 \, k\Omega$$
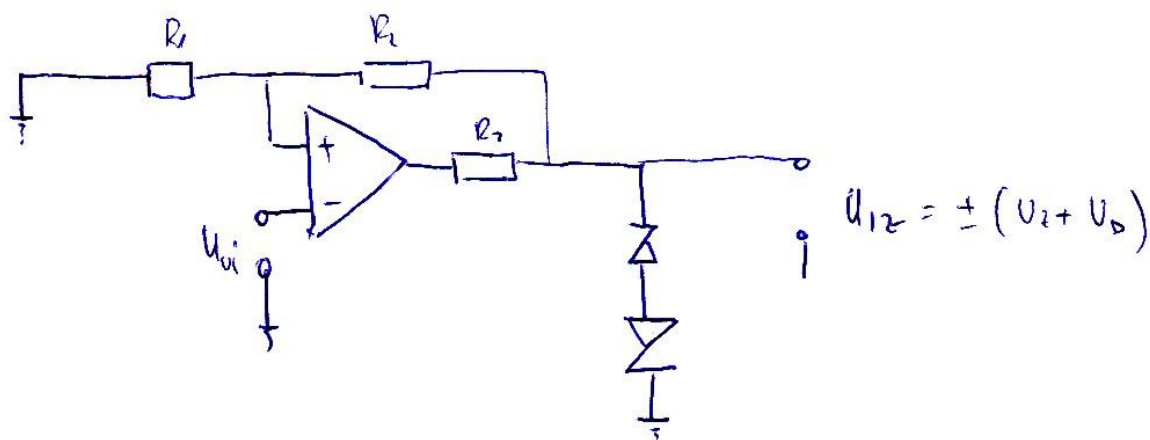
ELE 18

	SZE	SZB	SZC
A_V	$< \phi$ malo veliki	$> \phi$ moie velko	$> \phi \approx 1$
A_I	$< \phi$ A_i velik	>0 $A_i < 1$	>0 A_i velik
R_{UL}	UGLAVNO VELIKO	mali ulazni otpor (izlaz E)	veliki ulazi otp.
R_{1z}	R_C	R_C	R_{1z} malo (izlaz E)

$(ZI = 1)$
$8.1.11$

KOMPARATOR (OPCIJA → TEORIJI

- KORISTI + POVRATNU VEZU

$$U_{iz} = \pm(U_z + U_D)$$

- USIMA SE UZORAK IZLAZNOG NAPONA NAKON ŠTO DJELIĆ
  I USPOREĐUJE SE SA NAPONOM DOVEDEN NA θ OP

$$- U_{iz} = -U_D - U_z$$

$$U_{iz} = \pm(U_z + U_D)$$

$$U_+ > U_-$$
$$U_{iz} = A_{voA}(U_+ - U_-)$$
$$= +U_{iz}$$
$$U_+ = +\beta U_{iz}$$