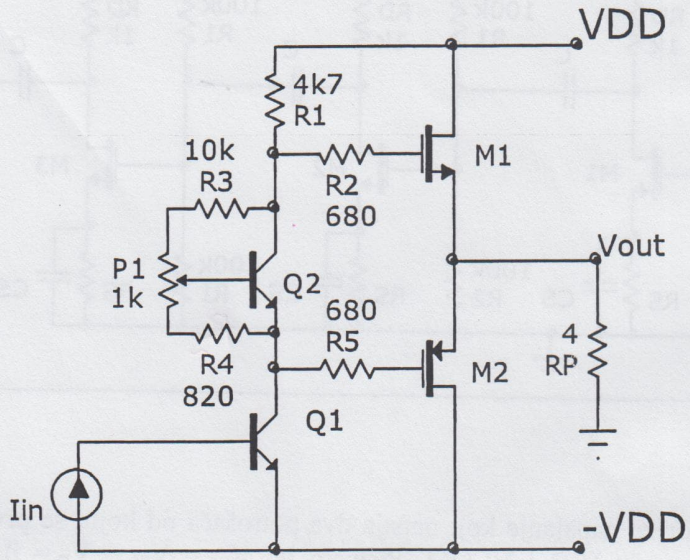
ZADATAK 1 25

Dat je pojačavač snage sa mosfetima na izlazu. Poznato je: $V_{DD} = 30$ V; $V_{BE} = 0{,}6$ V; $V_{CES} = 0{,}2$ V; $h_{FE} = \beta_{(Q1,Q2)} = 200$; $V_{TN} = -V_{TP} = 3$ V; $B_P = B_N = 1{,}1$ A/V^2;

10 a) Odrediti (srednju) snagu maksimalnog neizobličenog simetričnog (*sin*) signala na potrošaču,

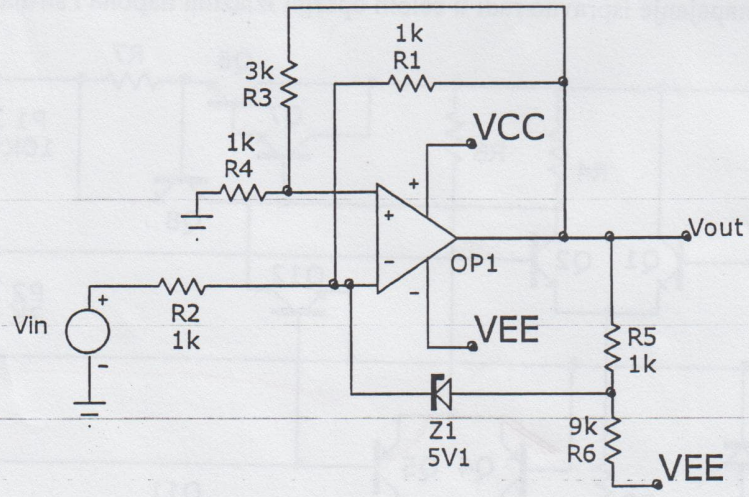
10 b) Podesiti položaj potenciometra P_1 tako da mirna radna struja M_1 i M_2 iznosi 100 mA,

5 c) Odrediti struju I_{in} za slučajeve kada je na potrošaču maksimalni simetrični neizobličeni napon na maksimumu, jednak nuli i minimumu.



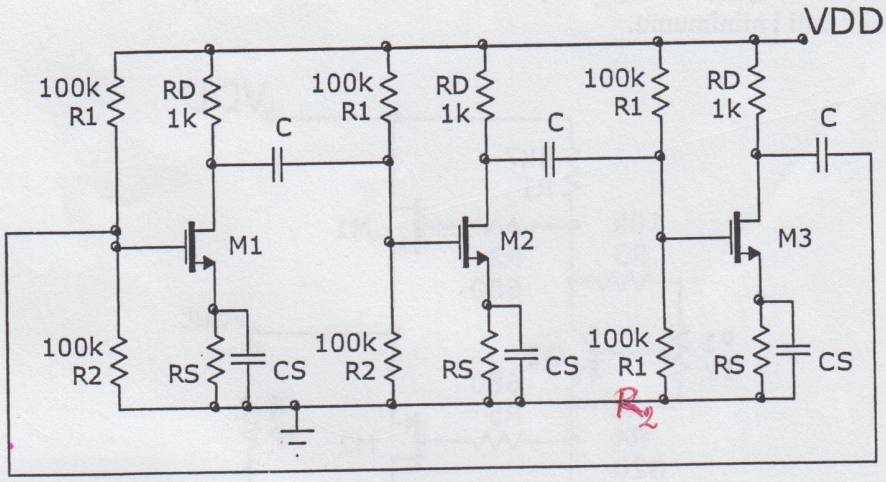
ZADATAK 2 25

Dato je kolo sa operacionim pojačavačem. Naći vezu između ulaznog napona V_{in} i izlaznog napona V_{out} i predstaviti ga grafički (V_{in} na horizontalnoj, V_{out} na vertikalnoj osi). Kolo analizirati u opsegu ulaznog napona V_{in} od -10 V do 10 V. Poznato je: $V_D = 0{,}6$ V; $V_{CC} = 15$ V; $V_{EE} = -15$ V; probojni napon Cener diode Z_1 iznosi 5,1 V.



ZADATAK 3 25

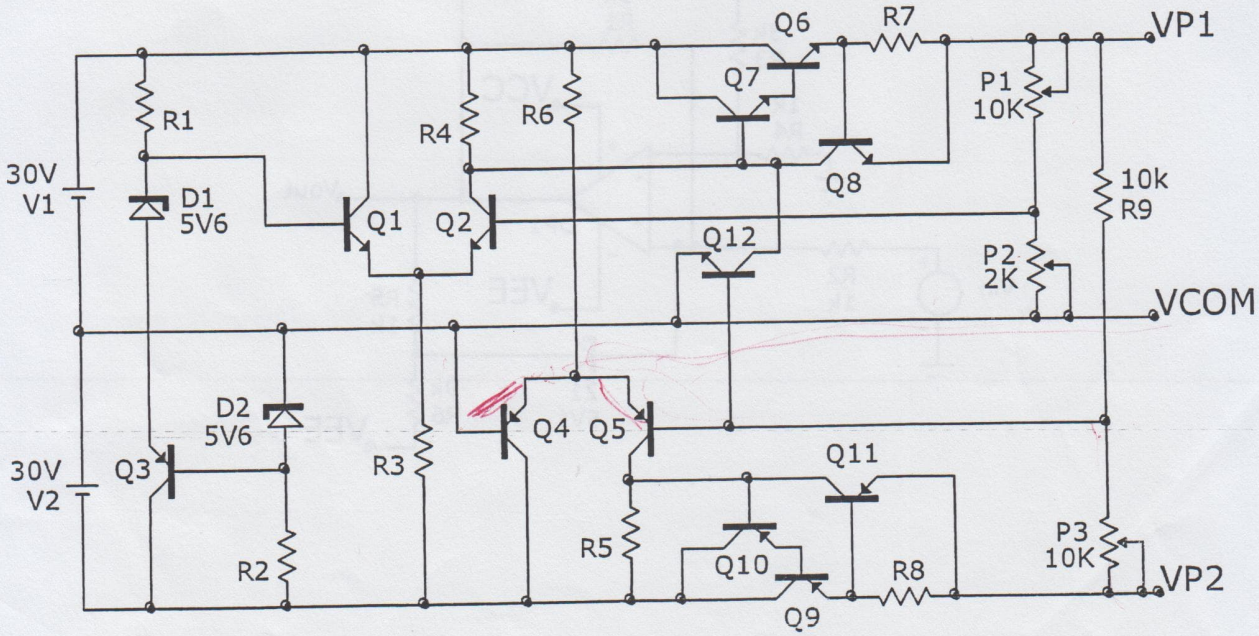
Dat je oscilator sa mosfetima. Odrediti kapacitivnost kondenzatora C i uslov koji treba da zadovolji otpornik R_S tako da frekvencija oscilovanja bude 1 kHz, a kolo može samostalno da započne oscilacije. Kondenzatori C_S imaju veoma velike kapacitivnosti. Poznato je: $V_{DD} = 12$ V; $B_1 = B_2 = B_3 = B = 1{,}3$ mA/V^2; $V_{T1} = V_{T2} = V_{T3} = V_T = 3$ V; mosfetovi se u zasićenju ponašaju u skladu sa $i_D = B(v_{GS} - V_T)^2$.



ZADATAK 4 25

Na sici je dat linearni izvor za napajanje koji napaja dva potrošača od kojih se prvi priključuje između VP1 i VCOM, a drugi između VP2 i VCOM. Poznato je: $V_{BE} = V_{EB} = V_D = 0{,}6$ V, $\beta_6 = \beta_9 = 30$ za tranzistore Q_6 i Q_9, dok je za sve ostale $h_{FE} = \beta = 150$. Probojni naponi Cener dioda D_1 i D_2 iznose 5,6 V.

a) Odrediti položaj potenciometra P_2 tako da maksimalni izlazni napon VP1 bude 25 V. Čime se podešava izlazni napon VP1 i koja je njegova minimalna vrednost?
b) Na koji način i u kom opsegu se može podesiti napon VP2?
c) Podesiti odgovarajuće otpornike da maksimalna struja oba potrošača bude ograničena na 1,6 A. Objasniti ulogu Q_{12}.
d) Odrediti otpornosti svih preostalih otpornika čija vrednost nije data na šemi tako da Cener diode imaju struju od 15 mA, a napajanje ispravno radi u celom opsegu izlaznih napona i struja potrošača.



1

a) Za M_2 vrijedi:

$$-V_{DD} + V_{CES} + V_{SG_2} + I_{D_2} R_p = 0 \quad \dots 3$$

$$I_{D_2} R_p = R_p B (V_{SG_2} - V_T)^2$$

$V_T = V_{TN} = V_{TP} = 3\,V$

$V_{SD} \geq V_{SG} - |V_{TP}|$ ... 2

$V_{SG_{11}} = 5{,}357\,V$ & ~~$V_{SG_{12}} = 0{,}41\,V$~~

$V_{pmin} = -V_{DD} + V_{CES_1} + V_{SG_1} = -24{,}443\,V$

$I_{pmin} = -\frac{V_{pmin}}{R_p} = -6{,}11\,A$ ... 3

$I_{pmax} = 6{,}11\,A$

$V_{pmax} = 24{,}443$

Za M_1 vrijedi

$$V_{DD} - V_{GS_1} - I_{D_1} R_p = 0$$

$$I_{D_1} R_p = R_p B (V_{GS_1} - V_T)^2$$

$V_{GS_1} = 5{,}366\,V$ (drugo rješenje nije moguće)

$V_{pmax} = V_{DD} - V_{GS_1} = 24{,}63\,V$

$I_{pmax} = \frac{V_{pmax}}{R_p} \doteq 6{,}16\,A$

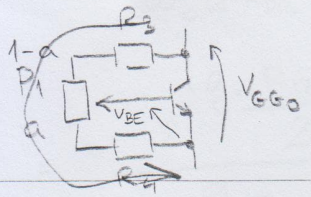
$V_{DS} \geq V_{GS} - |V_{TN}|$

$|V_{pmin}| > |V_{pmax}| \Rightarrow$ ograničenje je kod M_2

Za simetričan izlaz: $P_{max} = \frac{|V_{pmin}|^2}{2 R_p} = 74{,}8\,W$ ... 2

b.) $I_{D_0} = 100\,mA$

$V_{GS_0} = V_T \pm \sqrt{\frac{I_{D_0}}{B}}$ → $3{,}302\,V$ ~~$2{,}7\,V$~~ $\Rightarrow V_{GG_0} = 2 \cdot V_{GS_0} = 6{,}604$ ... 2



I_B - pretpostavimo da možemo zanemariti *

$$V_{GG_0} = (R_3 + R_4 + P_1) \frac{V_{BE}}{a P_1 + R_4}$$

$$a P_1 + R_4 = \frac{V_{BE}}{V_{GG_0}} (R_3 + R_4 + P_1)$$

$$a = \frac{1}{P_1} \left(\frac{V_{BE}}{V_{GG_0}} (R_3 + R_4 + P_1) - R_4 \right) = 0{,}254 \quad \dots 4$$

* $I_{R_1} = \frac{V_{DD} - V_{GS_0}}{R_1} = 5{,}68\,mA$

$I_{R_3} = \frac{V_{GG_0}}{R_3 + R_4 + P_1} = 558\,\mu A$ $\quad I_{C_2} = I_{R_1} - I_{R_3} = 5{,}122\,m \Rightarrow I_{B_2} = \frac{I_{C_2}}{\beta} = 25{,}6\,\mu A$

$I_{R_3} \gg I_{B_2}$ 21,8x veće ... 4

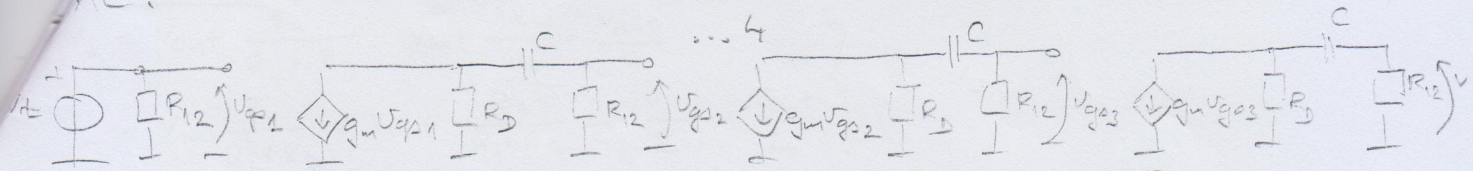
c.) $I_{in_0} = \frac{I_{R_0}}{\beta} = 28{,}4\,\mu A$ - za multi izlaz ... 2

$I_{in_{max}}$: $V_{GS_{1max}} = V_T \pm \sqrt{\frac{I_{pmax}}{B}} = 5{,}357\,V$ $\quad I_{C_1}' = \frac{V_{DD} - V_{GS_{1max}} - V_{pmax}}{R_1} = 425\,\mu A$

$I_{in_{max}} = \frac{I_{C_1}}{\beta} = 0{,}213\,\mu A$ - za maximalan odziv ... 2

$I_{G_1|max} = \frac{V_{DD} - V_{GG_0} - V_{CE} + V_{DD}}{\quad} \quad 11{,}32 \quad I_{in} = \frac{I_{C_1 max}}{\beta}$ ... 1

AC:



$R_{12} = R_1 \| R_2$ $\quad g_{m1} = g_{m2} = g_{m3} = g_m$ ... 1 $\quad A\beta = \frac{v_r}{v_t} = \frac{v_r}{v_{gs3}} \frac{v_{gs3}}{v_{gs2}} \frac{v_{gs2}}{v_{gs1}} v_t$

Sve tri selekcije su iste, pa sledi $T = \frac{v_r}{v_{gs3}} = \frac{v_{gs3}}{v_{gs2}} = \frac{v_{gs2}}{v_t} \Rightarrow A\beta = T^3$

$$v_{gs2} = -g_m R_{12}' \frac{R_D}{R_D + R_{12} + \frac{1}{sC}} v_t \Rightarrow T(s) = \frac{v_{gs2}}{v_t} = -\frac{g_m R_{12} R_D sC}{1 + sCR_{D12}}$$

$R_{D12} = R_D + R_{12}$

$(a+b)^3 = a^3 + 3a^2b + 3ab^2 + b^3$

$$A\beta(j\omega) = T^3(j\omega)$$

$$A\beta(j\omega) = \frac{(-g_m R_{12} R_D)^3 (j\omega C)^3}{(1 + j\omega C R_{D12})^3} = \frac{j(g_m R_{12} R_D)^3 \omega^3 C^3}{1 - 3\omega^2 C^2 R_{D12}^2 + j(3\omega C R_{D12} - \omega^3 C^3 R_{D12}^3)} \quad \text{... 6}$$

$A\beta(\omega_0) \in \mathbb{R} \Rightarrow 1 - 3\omega_0^2 C^2 R_{D12}^2 = 0$

$$\omega_0 = \frac{1}{\sqrt{3}\, C R_{D12}}$$

za $f_0 = 1\,kHz$

$$f_0 = \frac{1}{2\pi\sqrt{3}\, C (R_D + R_1 \| R_2)} \quad \text{... 3} \Rightarrow C = 1{,}8\,nF \quad \text{... 1}$$

$A\beta(\omega_0) \geq 1$

$$A\beta(\omega_0) = \frac{(g_m R_{12} R_D)^3 \omega_0^2 C^2}{\omega_0 C R_{D12} (3 - \omega_0^2 C^2 R_{D12}^2)} = \frac{(g_m R_{12} R_D)^3 \frac{1}{3C^2 R_{D12}^2} C^2}{\left(3 - \frac{C^2 R_{D12}^2}{3C^2 R_{D12}^2}\right) R_{D12}} =$$

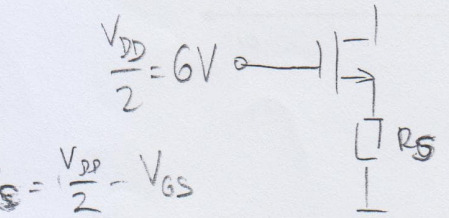
$$= \frac{\frac{(g_m R_{12} R_D)^3}{3 R_{D12}^2}}{\frac{9 - 1}{3} R_{D12}} = \frac{(g_m R_{12} R_D)^3}{8 R_{D12}^3} \geq 1 \quad \Big| \sqrt[3]{}$$

$$g_m \geq \frac{2(R_D + R_1 \| R_2)}{(R_1 \| R_2) R_D} \Leftarrow \frac{g_m R_{12} R_D}{2 R_{D12}} = \frac{g_m (R_1 \| R_2) R_D}{2(R_D + R_1 \| R_2)} \geq 1 \quad \text{... 3}$$

$g_m \geq 2{,}04\,mS$ ... 1 $\quad B = 1{,}3\,m\frac{A}{V^2}$; $V_T = 3V$

$g_m = 2\sqrt{B I_D} \rightarrow g_m^2 = 4 B I_D \Rightarrow I_D = \frac{g_m^2}{4B}$

$I_D = \frac{2{,}04\,m^2}{4 \cdot 1{,}3\,m} = 800\,\mu A$ ... 2



$I_D = B(V_{GS} - V_T)^2$

$V_{GS} - V_T = \pm\sqrt{\frac{I_D}{B}}$

$V_{GS} = V_T + \sqrt{\frac{I_D}{B}} = 3{,}78V$ ... 2

$I_D R_S = \frac{V_{DD}}{2} - V_{GS}$

$R_S = \frac{6 - 3{,}78}{800\,\mu} = 2775\,\Omega$ ... 2

Z_1 ne vodi (A)

$$V_+ = V_{out}\frac{R_4}{R_4+R_3} = V_{out}\frac{1k}{4k} = \frac{V_{out}}{4}$$

$$V_- = V_{in}\frac{R_1}{R_1+R_2} + V_{out}\frac{R_2}{R_1+R_2} = \frac{V_{in}}{2} + \frac{V_{out}}{2}$$

$\Big\}\ V_+ = V_-$

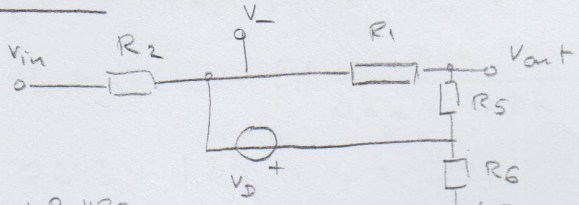
$$\frac{V_{out}}{4} = \frac{V_{in}}{2} + \frac{V_{out}}{2} \quad \Big| \cdot 4$$

$$V_{out} = 2V_{in} + 2V_{out} \Rightarrow \underline{V_{out} = -2V_{in}}$$

... 3

Z_1 vodi u direktnom smeru (B)

$$V_+ = \frac{V_{out}}{4}$$



$$V_- = V_{in}\frac{R_1\|R_5\|R_6}{R_1\|R_5\|R_6+R_2} + V_{EE}\frac{R_1\|R_2\|R_5}{R_1\|R_2\|R_5+R_6} +$$

$$+ \frac{R_2\|R_5}{R_2\|R_6+R_1\|R_5}V_{out} - \frac{R_1\|R_2}{R_1\|R_2+R_5\|R_6}V_D$$

$$= V_{in}\frac{0{,}462k}{0{,}462k+1k} - 15\frac{0{,}33k}{0{,}33k+9k} + V_{out}\frac{0{,}9k}{0{,}9k+0{,}5k} - 0{,}6\frac{0{,}5k}{0{,}5k+0{,}9k}$$

$$= V_{in}\cdot 0{,}316 - 0{,}53 + V_{out}\cdot 0{,}643 - 0{,}214 =$$

$$= V_{in}\cdot 0{,}316 + V_{out}\cdot 0{,}643 - 0{,}744 = V_+ = \frac{V_{out}}{4}$$

$$V_{out}(0{,}643 - 0{,}25) = -V_{in}\cdot 0{,}316 + 0{,}744$$

$$\boxed{V_{out} = -0{,}804\,V_{in} + 1{,}893} = V_{out}'$$ ← za nalaženje tačke preseka

$V_{out}' = V_{out}$ (pod A)

$V_{out}(-10) = -0{,}804(-10) + 1{,}893 = 9{,}933\ V$

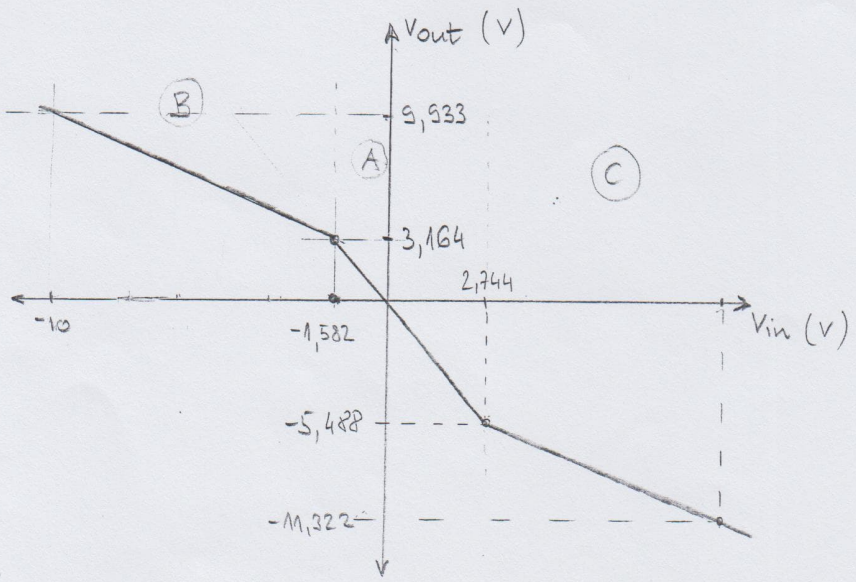
$$-2V_{in} = -0{,}804\,V_{in} + 1{,}893$$

$$(-2 + 0{,}804)V_{in} = 1{,}893 \Rightarrow V_{in} = -1{,}582\ V$$

... 9

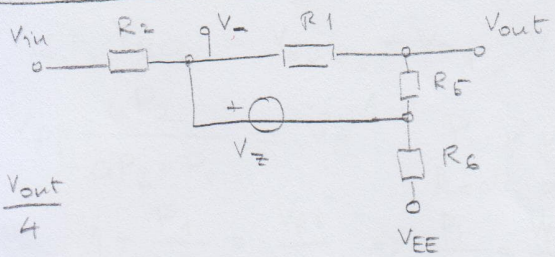
provera: $V_{out(A)} = -2V_{in} = -2(-1{,}582) = 3{,}164\ V$

$V_{out(B)} = -0{,}804\,V_{in} + 1{,}893 = 3{,}165\ V$



... 4

Z_1 vodi u proboju (c)



$V_+ = \frac{V_{out}}{4}$

$$V_- = V_{in}\frac{R_1 \| R_5 \| R_6}{R_1 \| R_5 \| R_6 + R_2} + V_{EE}\frac{R_1 \| R_2 \| R_5}{R_1 \| R_2 \| R_5 + R_6} + V_{out}\frac{R_2 \| R_6}{R_2 \| R_6 + R_1 \| R_5} + V_z\frac{R_1 \| R_2}{R_1 \| R_2 + R_5 \| R_6} =$$

$$= V_{in} \cdot 0{,}316 - 0{,}53 + V_{out} \cdot 0{,}643 + 5{,}1\frac{0{,}5k}{0{,}5k + 0{,}9k} =$$

$$= V_{in} \cdot 0{,}316 + V_{out} \cdot 0{,}643 + 1{,}29 = V_+ = \frac{V_{out}}{4}$$

$$V_{out}(0{,}643 - 0{,}25) = -V_{in} \cdot 0{,}316 - 1{,}29$$

$$V_{out} \cdot 0{,}393 = -V_{in} \cdot 0{,}316 - 1{,}29$$

$$\boxed{V_{out} = -0{,}804\, V_{in} - 3{,}282} = V_{out}' \quad \text{preseka sa delom A}$$

$V_{out}' = V_{out}$ (pod A)

9

$$-2 V_{in} = -0{,}804\, V_{in} - 3{,}282$$

$$-1{,}196\, V_{in} = -3{,}282 \Rightarrow V_{in} = 2{,}744\ V$$

provera: $-2 V_{in} = -2 \cdot 2{,}744 = -5{,}488\ V$

$-0{,}804\, V_{in} - 3{,}282 = -5{,}488\ V$ ✓

$V_{out}(10V) = -0{,}804 \cdot 10 - 3{,}282 = 11{,}322\ V$

a.)

$$V_R = V_{BQ_1} = V_{EBQ_3} + V_{Z_1} - V_{Z_2} = V_{EB} = 0,6\,V \quad \dots 2$$

$$V_{P_1}\frac{aP_2}{aP_2+P_1} = V_R \quad \dots 1$$

P_1 je u položaju maksimalne otpornosti kada daje maksimalni izl. napon

$$1+\frac{P_1}{aP_2} = \frac{V_{P1}}{V_R} \Rightarrow \frac{P_1}{aP_2} = \frac{V_{P1}}{V_R} - 1 \Rightarrow aP_2 = \frac{P_1}{\frac{V_{P1}}{V_R}-1} \Rightarrow a = \frac{P_1}{P_2\left(\frac{V_{P1}}{V_R}-1\right)}$$

za $V_{P_1} = 25\,V \Rightarrow \underline{a = 0,123}$

Napon V_{P_1} se podešava pomoću P_1 1

$$\rightarrow V_{P_1} = V_R\left(1+\frac{bP_1}{aP_2}\right) = \begin{cases} \nearrow V_R = 0,6\,V \text{ za } b=0 \\ \searrow 25\,V \text{ za } b=1 \end{cases} \quad \dots 5$$

b) V_{P_2} se podešava potenciometrom P_3.

$$V_{BQ_4} = 0 = V_{BQ_5} = V_{P_2} + (V_{P_1} - V_{P_2})\frac{cP_3}{cP_3+R_9}$$

$$(cP_3+R_9)V_{P_2} - V_{P_2}cP_3 = -V_{P_1}cP_3 \quad \dots 5$$

$$V_{P_2}R_9 = -V_{P_1}cP_3 \Rightarrow V_{P_2} = -V_{P_1}\frac{cP_3}{R_9} = \underline{-cV_{P_1}}$$

$$\underline{V_{P_2} = -cV_{P_1}} \begin{cases} \nearrow 0\,V \text{ za } c=0 \\ \searrow -V_{P_1} \text{ za } c=1 \end{cases} \begin{cases} \rightarrow -0,6 \text{ za } b=0 \\ \rightarrow -25 \text{ za } b=1 \end{cases}$$

c.)

$$R_7 = \frac{V_{BE}}{I_{Bmax}} = R_8 = \underline{0,375\,\Omega} \quad \dots 5$$

Q_{12} isključi Q_7 i Q_6 u slučaju da struja ograničenja krene da obara napon na V_{P_2}. Time struja zaštita postaje simetrična.

d.)

$$V_1 - I_{D_1}R_1 - \cancel{V_{Z_1}} - V_{EB} + \cancel{V_{Z_2}} = 0$$

$$R_1 = \frac{V_1 - V_{EB}}{I_{D_1}} = \frac{30-0,6}{15m} = 1960\,\Omega \quad \left(\begin{matrix} I_{R_1max} = I_{C_1max} \\ I_{B_1max} << 15mA \end{matrix}\right)$$

$$R_2 = \frac{V_2 - V_{Z_2}}{I_{D_2}} = \frac{30-5,6}{15m} = 1627\,\Omega \quad (I_{C_3} = 15m \Rightarrow I_{B_3} = 100\mu << I_{D_2}) \quad \dots 4$$

R_4 treba da obezbedi barem struju za Q_7 i pri max. struji od 1,6A

$$V_1 - \frac{I_{P1}}{\beta_7\beta_6}R_4 - 2V_{BE} - I_{P_1}R_2 = V_{P_1max} \quad \text{najteži slučaj } I_{P_1} = I_{Pmax} = 1,6A$$

$$\frac{I_{P1}R_4}{\beta_7\beta_6} = 3,2\,V \Rightarrow R_4 \leq 9k\Omega \quad , \left(I_{R_4} = \frac{I_{P1}}{\beta_7\beta_6} = 355\mu A\right)$$

R_3 treba da ima istu struju da bi mogao da balansira

$$I_{R_4} = \frac{3,2V}{R_4} \qquad I_{R_3} = \frac{V_R - V_{BE} - V_2}{R_3} = \frac{30}{R_3} \geq \frac{3,2}{R_4} \Rightarrow R_3 \leq \frac{30}{3,2}\cdot R_4 = 84,4k\Omega$$

Pod potpuno istim okolnostima se nalaze i R_5 i R_6. $(V_1 = V_2, \beta_6 = \beta_7, V_{P_1max} = -V_{P_2max})$ $\dots 6$

Zato $R_5 \leq 9k\Omega$, $R_6 \leq \frac{30}{3,2}R_5 = 84,4k\Omega$