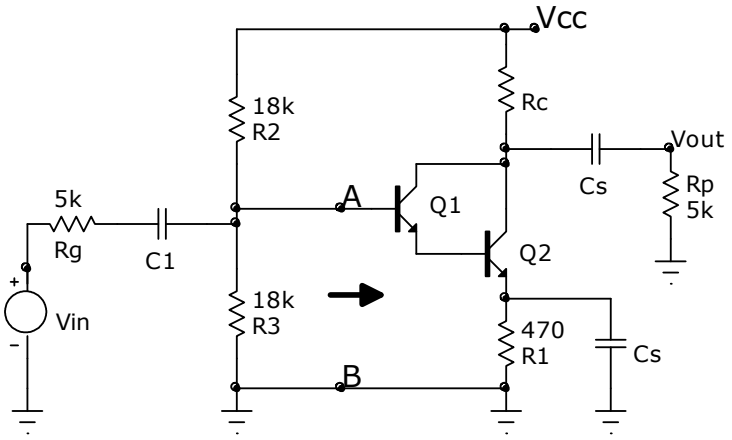
ZADATAK 1

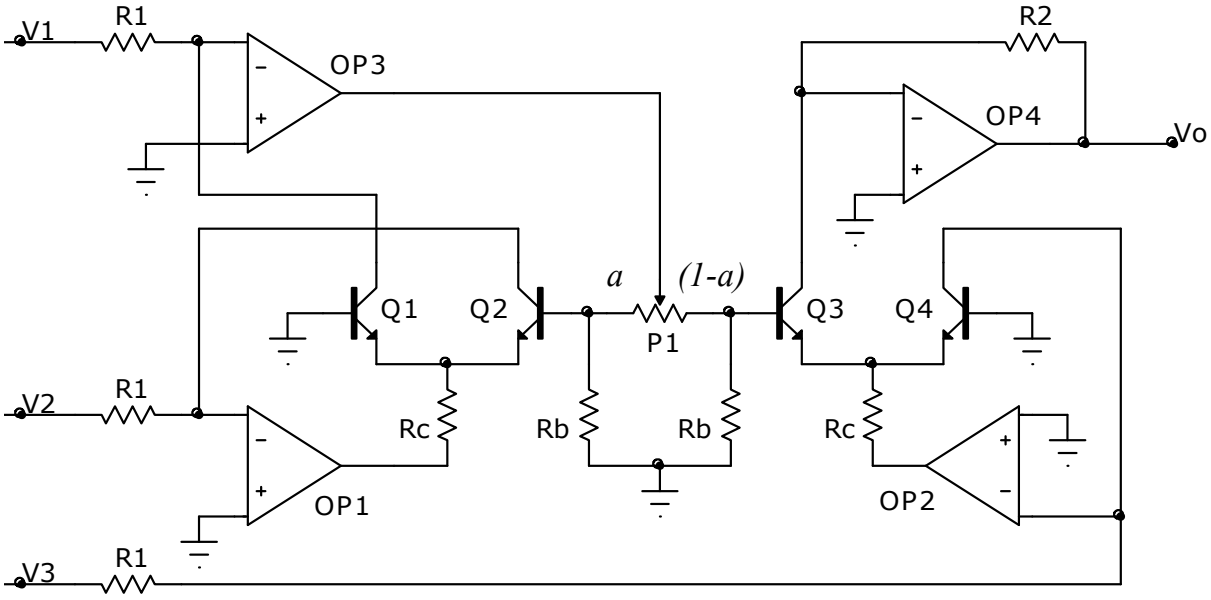
Dato je pojačavačko kolo sa bipolarnim tranzistorima. Poznato je V_{BE} = 0,6 V; V_{CES} =0,2 V; V_T = 25 mV; $\beta_1 = \beta_2 = \beta = 105$; V_{CC} = 9 V; $V_A \rightarrow \infty$.

a) Odrediti otpornost koju bi video naizmenični generator između tačaka A i B u smeru strelice (ako se levi deo kola ukloni),
b) Odrediti Rc tako da jednosmerni napon kolektora Q1 i Q2 bude 6 V u odnosu na masu,
c) Izračunati naponsko pojačanje V_{out} / V_{in} (za Rc izračunato pod b).



ZADATAK 2

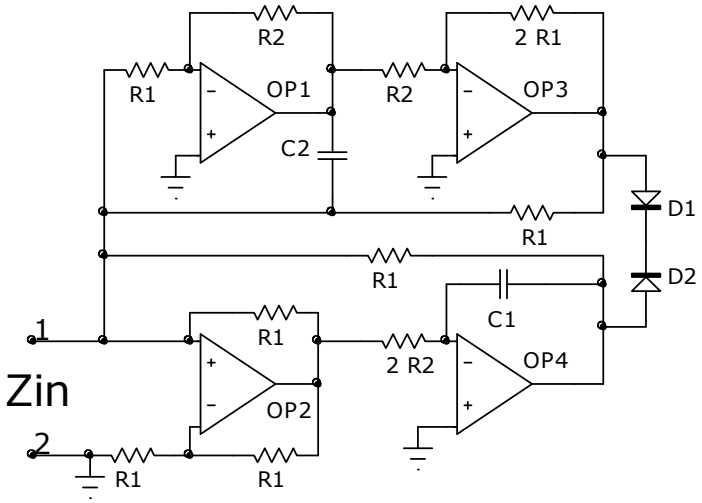
Dato je kolo sa idealnim operacionim pojačavačima i bipolarnim tranzistorima. Naći zavisnost izlaznog napona Vo u zavisnosti do parametara kola (R1, R2, Rb i Rc), položaja klizača potenciometra P1 ($0 \leq a \leq 1$) i ulaznih napona V1, V2 i V3. Svi tranzistori su identičnih karakteristika, V_T=25 mV, $\beta >> 1$.



ZADATAK 3

Dato je kolo sa idealnim operacionim pojačavačima. Poznato je: V_D=0,6 V; R_1 = 10 kΩ; R_2 = 18 kΩ; C_1 = 1 nF; C_2 =10 nF. Oznaka 2 R_1 ili 2 R_2 znači da otpornik ima 2 puta veću otpornost u odnosu na R_1 ili R_2.

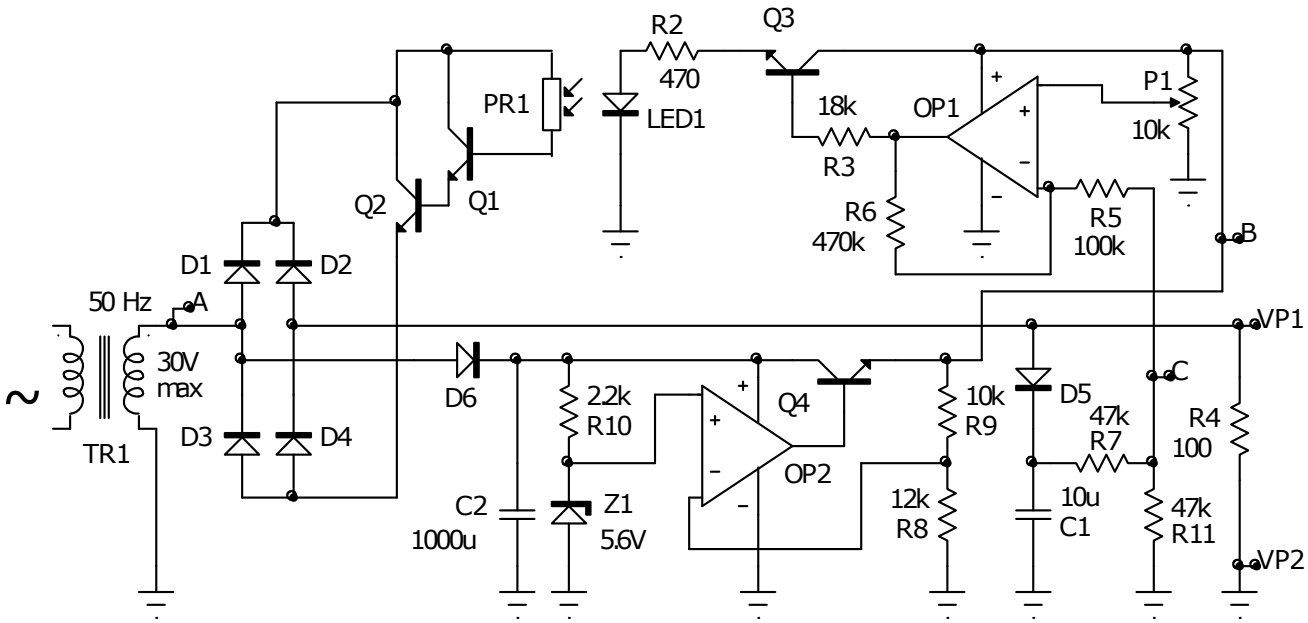
a) Odrediti (formulu za) impedansu koja se vidi između tačaka 1 i 2 (Zin),
b) Ako se na ovo mesto dovede prostoperiodična (sinusna) naponska pobuda nenulte amplitude, na kojoj frekvenciji će struja biti nulte vrednosti?



ZADATAK 4

Dato je specijalno kolo za napajanje potrošača koji se priključuje između tačaka VP1 i VP2. Vrednosti komponenti upisane su na šemi, „u" je oznaka koja stoji umesto μ. Par kojeg čine LED1 i foto-otpornik PR1 predstavlja specijalni optički sprežni element. U zavisnosti od svetlosti LED-a koja *jedina* osvetljava fotootpornik menja se njegova otpornost i to približno u skladu sa sledećom formulom: $R = 990\,\Omega\, A\left(1/x^{0,8}\right)$. Kada je fotootpornik potpuno neosvetljen, smatrati da je njegova otpornost 5 MΩ. U svim analizama smatrati da su naponi provodnih dioda i naponi između baze i emitera provodnih tranzistora 0 V. Maksimalni i minimalni izlaz operacionih pojačavača odgovara njihovim naponima napajanja. β_2 = 50, svi ostali tranzistori: β = 120. Na sekundaru transfomatora je sinusni napon fiksne maksimalne vrednosti od V_{Smax} = 30 V

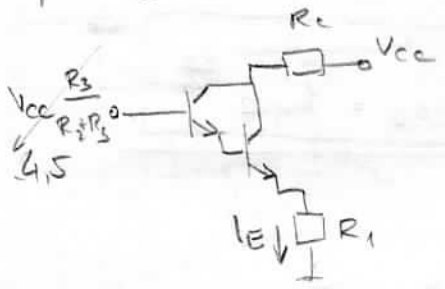
a) Skicirati vremenske oblike napona u tačkama A, B, C i VP1 ako je P1 u srednjem položaju.
b) Odrediti minimalni napon koji se može podesiti u odsustvu potrošača?
c) Koji je maksimalni napon moguće podesiti na potrošaču od 8 Ω?



(1)

Da bi se dec pod a rešio neophodno je prvo ustanoviti DC režim rada.

Pretpostavimo da se bazna struja može zanemariti u odnosu na struje R_2 i R_3 *

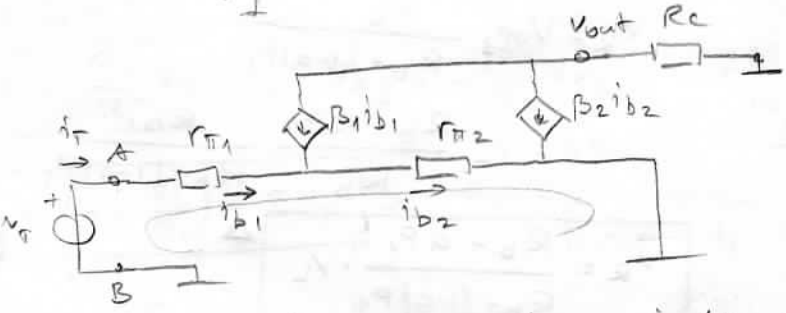


$$I_{C_1} + I_{C_2} = I_{G_1}$$

$$I_{E_1} = \frac{4,5 - 2V_{BE}}{R_1} = 7mA$$

$$I_{R_c} = I_E = 7mA \quad \ldots 6$$

a.)



* dokaz

$$I_{B_1} \approx \frac{I_E}{\beta_1 \beta_2} = 635nA$$

$$I_{R_{12}} = \frac{V_{cc}}{R_2 + R_3} = 250\mu A$$

$$i_T = i_{b_1} \qquad i_{b_2} = i_{b_1} + \beta_1 i_{b_1} = i_{b_1}(\beta_1 + 1)$$

$$V_T = i_T\left[r_{\pi_1} + (\beta_1 + 1) r_{\pi_2}\right]$$

$$R_{AB} = \frac{V_T}{i_T} = r_{\pi_1} + (\beta_1 + 1) r_{\pi_2}$$

$$I_E \approx I_{C_2} \Rightarrow r_{\pi_2} = \beta_2 \frac{V_T}{I_{C_2}} = 105 \frac{25m}{7m} = 375\Omega$$

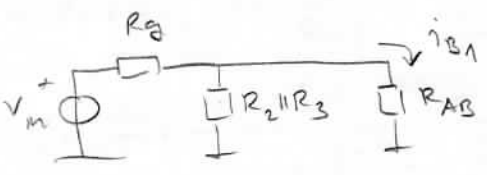
$$I_{C_1} = \frac{I_{C_2}}{\beta_2} = 67\mu A \Rightarrow r_{\pi_1} = \beta_1 \frac{25m}{67\mu} = 39,18k\Omega$$

$$R_{AB} = 39,18k + (105+1)375 = 78,93k\Omega \quad \ldots 7$$

b.)

$$V_c = V_{cc} - (I_{C_1} + I_{C_2}) R_c = 6V \Rightarrow R_c = \frac{V_{cc} - 6V}{I_E} = 428,6\Omega \quad \ldots 6$$

c.)



$$i_{B_1} = \frac{V_{in} \cdot R_2 \| R_3 \| R_{AB}}{R_g + R_2 \| R_3 \| R_{AB}} \cdot \frac{1}{R_{AB}} = \frac{0,618\, V_{in}}{R_{AB}}$$

($R_2 \| R_3 \| R_{AB} \approx 8,08k$, $R_g + R_2 \| R_3 \| R_{AB} \approx 8,08k$)

$$V_{out} = -R_c(\beta_1 i_{b_1} + \beta_2 i_{b_2}) = -R_c\left(\beta_1 i_{b_1} + \beta_2(\beta_1+1) i_{b_1}\right)$$

$$i_{b_2} = i_{b_1} + \beta_1 i_{b_1} = i_{b_1}(\beta_1 + 1)$$

$$V_{out} = -R_c\, i_{b_1}\left(\beta_1 + \beta_2(\beta_1+1)\right)$$

$$V_{out} = -428,6 \cdot (105 + 105 \cdot 106) \cdot \frac{0,618}{78,93k} \cdot V_{in}$$

$$A_V = -37,7 \quad \ldots 6$$

2.

V_L - baza Q_2 , V_R - baza Q_3

$$V_L = V_{BE_2} - V_{BE_1}$$

$$i_c = I_S e^{\frac{V_{BE}}{V_T}} \Rightarrow V_{BE} = V_T \ln \frac{i_c}{I_S}$$

$$\Rightarrow V_L = V_T \ln \frac{\frac{i_{c2}}{I_S}}{\frac{i_{c1}}{I_S}} = \boxed{V_T \ln \frac{i_{c2}}{i_{c1}} = V_L} \quad *$$

6

$$V_R = V_{BE_3} - V_{BE_4} \Rightarrow V_R = V_T \ln \frac{i_{c3}}{i_{c4}}$$

$$\frac{V_R}{V_T} = \ln \frac{i_{c3}}{i_{c4}} \Rightarrow e^{\frac{V_R}{V_T}} = e^{\ln \frac{i_{c3}}{i_{c4}}} \Rightarrow \boxed{i_{c3} = i_{c4} e^{\frac{V_R}{V_T}}} \quad \square$$

6.

V_{OP_3} - izlaz OP_3

$$V_L = V_{OP_3} \frac{R_b}{R_b + aP_1} \qquad V_R = V_{OP_3} \frac{R_b}{R_b + (1-a)P_1}$$

$$\Rightarrow V_{OP_3} = V_L \frac{R_b + aP_1}{R_b}$$

$$V_R = V_L \frac{R_b + aP_1}{R_b} \cdot \frac{R_b}{R_b + (1-a)P_1}$$

$$\boxed{V_R = \frac{R_b + aP_1}{R_b + (1-a)P_1} \cdot V_L} \quad \Delta$$

8

k

na osnovu *, □ i Δ

$$i_{c3} = i_{c4} e^{\left[\frac{1}{V_T} k V_L\right]} =$$

$$= i_{c4} e^{\left[\frac{1}{V_T} k V_T \ln \frac{i_{c2}}{i_{c1}}\right]} = i_{c4} \left(\frac{i_{c2}}{i_{c1}}\right)^k$$

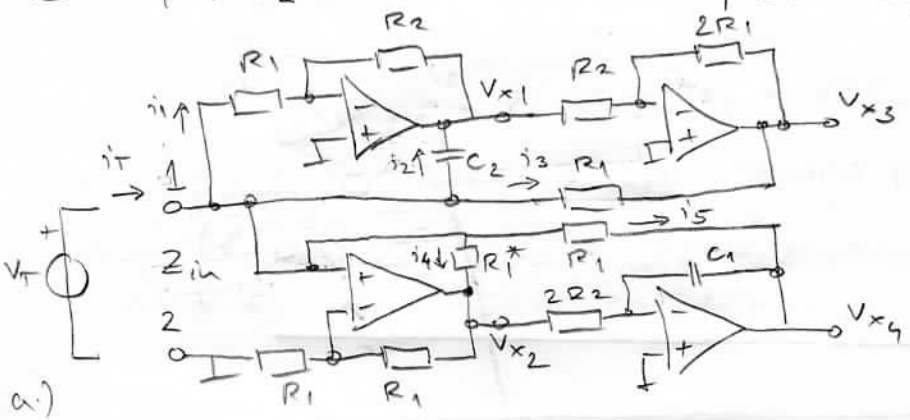
$$i_{c1} = \frac{V_1}{R_1} \; ; \; i_{c2} = \frac{V_2}{R_1} \; ; \; i_{c4} = \frac{V_3}{R_1}$$

$$V_o = R_2 i_{c3}$$

$$V_o = R_2 \frac{V_3}{R_1} \left(\frac{\frac{V_2}{R_1}}{\frac{V_1}{R_1}}\right)^k = \frac{R_2}{R_1} V_3 \left(\frac{V_2}{V_1}\right)^k = \frac{R_2}{R_1} V_3 \left(\frac{V_2}{V_1}\right)^{\frac{R_b + aP_1}{R_b + (1-a)P_1}}$$

5

(3.) D_1 i D_2 nikad nece voditi pa se mogu potpuno izostaviti.



a.)

$V_2 = 0 \quad ; \quad V_1 = V_T$

$$\boxed{V_{x_1} = -\frac{R_2}{R_1} V_T}^{a} \quad ; \quad V_{x_3} = -\frac{2R_1}{R_2} V_{x_1} = -\frac{2R_1}{R_2}\left(-\frac{R_2}{R_1}\right) V_1 = \boxed{2V_T = V_{x_3}}^{b}$$

$$\boxed{V_{x_2} = V_1\left(1 + \frac{R_1}{R_1}\right) = 2V_T}^{c}$$

*R_1 nije povratna sprega jer je V_1 naponski izvor, tj. tačka „uzdaj" potencijala

$$V_{x_4} = -\frac{\frac{1}{sC_1}}{2R_2} V_{x_2} = -\frac{1}{2sC_1R_2} V_{x_2} = -\frac{2V_1}{2sC_1R_2} = \boxed{-\frac{V_T}{sC_1R_2} = V_{x_4}}^{d} \quad \ldots 6$$

$$i_T = i_1 + i_2 + i_3 + i_4 + i_5$$

$$i_1 = \frac{V_T - 0}{R_1} = \frac{V_T}{R_1} \quad ; \quad i_2 = \frac{V_T - V_{x_1}}{\frac{1}{sC_2}} = sC_2\left(V_T + \frac{R_2}{R_1} V_T\right) = V_T\, sC_2\left(1 + \frac{R_2}{R_1}\right) \quad \ldots 6$$

$$i_3 = \frac{V_T - V_{x_3}}{R_1} = \frac{V_T - 2V_T}{R_1} = -\frac{V_T}{R_1} \quad ; \quad i_4 = \frac{V_T - V_{x_2}}{R_1} = \frac{V_T - 2V_T}{R_1} = -\frac{V_T}{R_1}$$

$$i_5 = \frac{V_T - V_{x_4}}{R_1} = \frac{V_T + \frac{V_T}{sC_1R_2}}{R_1} = V_T \frac{\frac{sC_1R_2 + 1}{sC_1R_2}}{R_1} = V_T \frac{1 + sC_1R_2}{sC_1R_1R_2}$$

$$i_T = V_T\left[\frac{1}{R_1} + sC_2\left(1 + \frac{R_2}{R_1}\right) - \frac{1}{R_1} - \frac{1}{R_1} + \frac{1 + sC_1R_2}{sC_1R_1R_2}\right] =$$

$$= V_T\left[sC_2\left(1 + \frac{R_2}{R_1}\right) - \frac{sC_1R_2 - 1 - sC_1R_2}{sC_1R_1R_2}\right] = V_T\left[sC_2\left(1 + \frac{R_2}{R_1}\right) + \frac{1}{sC_1R_1R_2}\right]$$

$$Z_{in} = \frac{V_T}{i_T} = \frac{1}{sC_2\left(1 + \frac{R_2}{R_1}\right) + \frac{1}{sC_1R_1R_2}} = \frac{sC_1R_1R_2}{1 + s^2C_1C_2R_1R_2\left(1 + \frac{R_2}{R_1}\right)} = \quad \ldots 6$$

$$= \frac{sC_1R_1R_2}{1 + s^2C_1C_2R_2(R_1 + R_2)}$$

b.) struja će biti nula ako je imenilac jednak nuli ($Z_{in} \to \infty$)

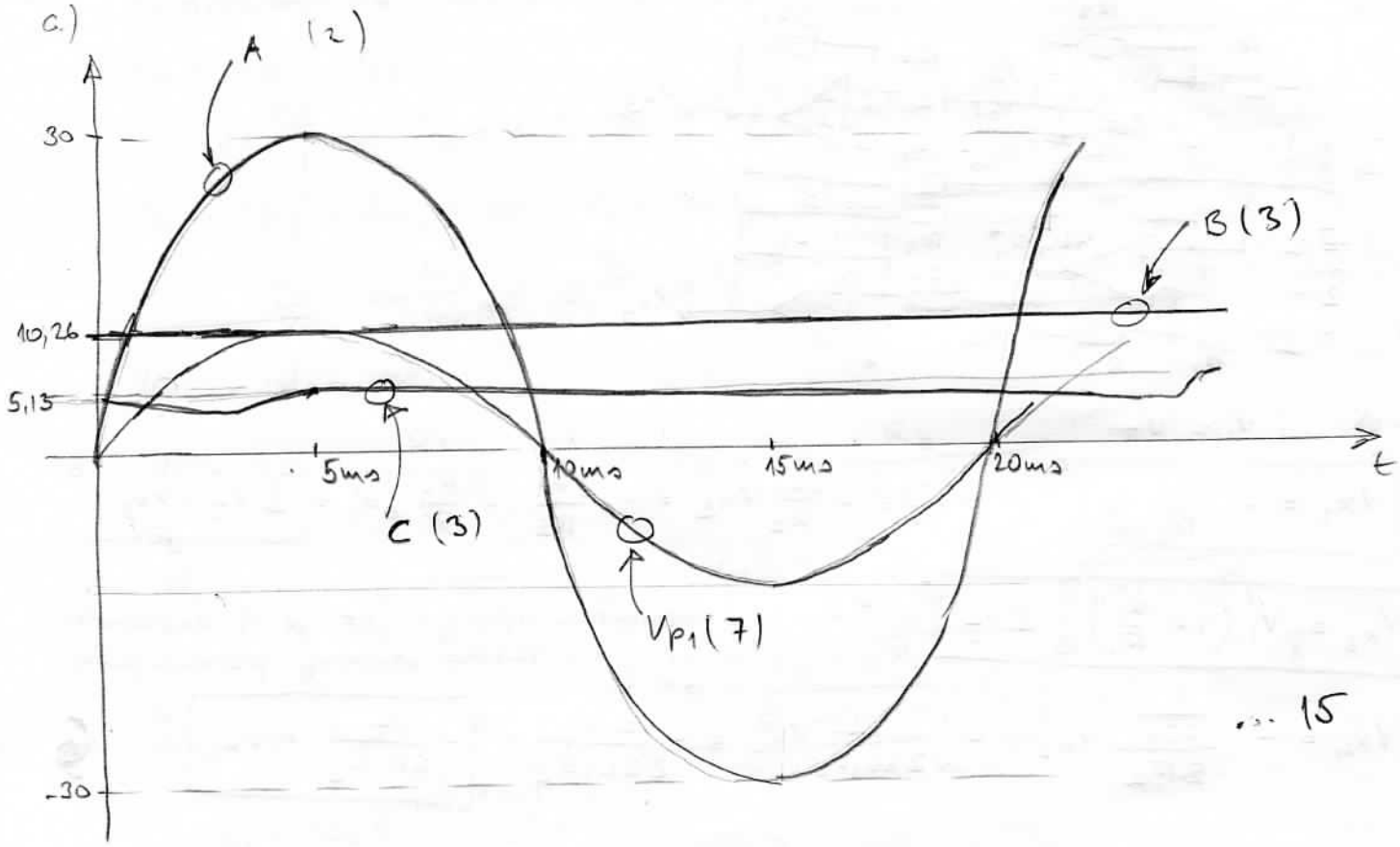
$s \to j\omega \qquad 1 - \omega^2 C_1C_2R_2(R_1 + R_2)$

$$\omega_0 = \frac{1}{\sqrt{C_1C_2R_2(R_1 + R_2)}} = 14{,}086 \cdot 10^{-3}\, s^{-1} \quad ; \quad f_0 = \frac{\omega_0}{2\pi} = 2{,}242\,kHz$$

$\ldots 7$

4.

a.)



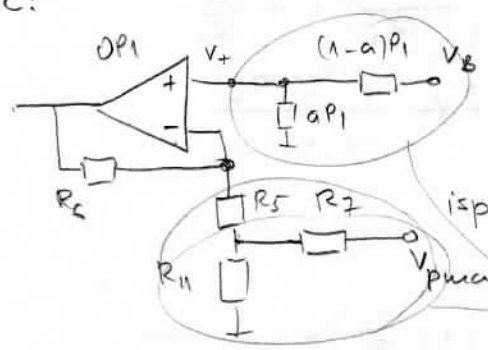
... 15

B:

$$V_{+2} = V_{Z1} = 5{,}6\,V \quad ; \quad V_{-2} = V_B \frac{R_8}{R_8 + R_9}$$

$$V_{+2} = V_{-2} \Rightarrow \quad 5{,}6 = V_B \frac{R_8}{R_8 + R_9} \Rightarrow V_B = 5{,}6\left(1 + \frac{R_9}{R_8}\right) = \boxed{10{,}26\,V = V_B}$$

C:

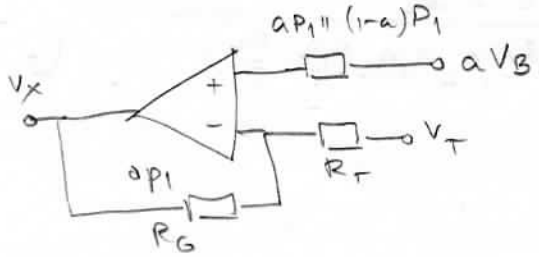


$a = 0{,}5 \Rightarrow V_+ = \frac{V_B}{2} = 5{,}13\,V$

ispravljeni izlazni napon (max. vrednost)

→ Terenen:

Diferencijalni pojačavač



$$V_T = V_{pmax} \frac{R_{11}}{R_7 + R_{11}} = \frac{V_{pmax}}{2}$$

$$R_T = R_5 + R_{11} \| R_7 = 123{,}5\,k\Omega$$

$$\left.\begin{aligned} V_+ &= aV_B \\ V_- &= \frac{R_T}{R_G + R_T} V_x + \frac{R_G}{R_T + R_G} V_T \end{aligned}\right\} \quad aV_B = \frac{R_T}{R_G + R_T} V_x + \frac{R_G}{R_G + R_T} V_T \quad \Big| R_G + R_T$$

$$(R_G + R_T)\,aV_B = R_T V_x + R_G V_T$$

$$V_x = \frac{R_G + R_T}{R_T} aV_B - \frac{R_G + R_T}{R_G} V_T$$

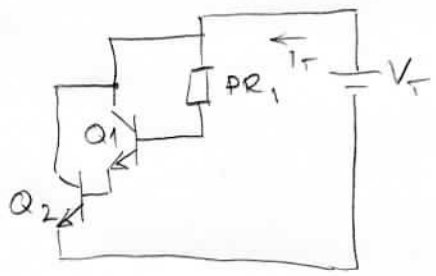
pojačavač izjednačava (poništava) V_T ($\frac{V_{pmax}}{2}$) i aV_B ($\frac{V_B}{2}$)

$$V_{pmax} = 2\,\frac{V_B}{2} = V_B = 10{,}26\,V$$

na napon C nočava se sporo pražnjenje kondenzatora
Zbog konačnog pojačanja diferencijalnog pojačavača ovaj proračun je samo približan.

b.)

Otpornost promenljive otpornika $LED_1 + PR1 + Q_1 + Q_2$: R_x



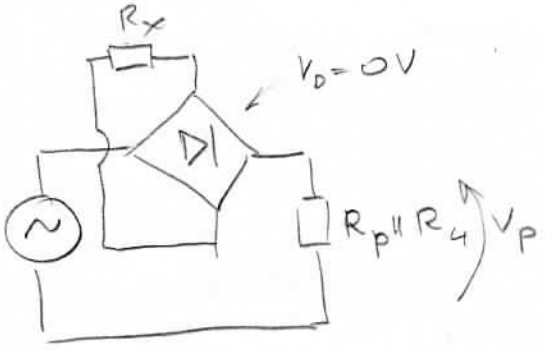
$$I_{B_1} = \frac{V_T - V_{BE_1} - V_{BE_2}}{PR_1}$$

$$I_{E_1} = (\beta_1 + 1)\, I_{B_1}$$

$$I_{E_2} = (\beta_2 + 1)\, I_{B_2} = (\beta_2 + 1)\, I_{E_1}$$

$$I_T = I_{E_2} = (\beta_1 + 1)(\beta_2 + 1)\,\frac{V_T}{PR_1}$$

$$R_x = \frac{PR_1}{(\beta_1+1)(\beta_2+1)} \approx \frac{PR_1}{\beta_1\beta_2} = \frac{PR_1}{6000}$$



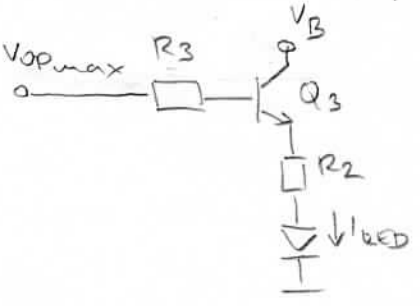
$$V_{Pm} = \frac{R_p \| R_4}{R_p \| R_4 + R_x} \cdot V_{sm}$$ – vršne vrednosti

za slučaj b.) imamo $R_x = R_{xmax}$, $R_p = \infty$

$R_{xmax} = \frac{5M\Omega}{6000}$ kada nema struje kroz LED1

$$V_{pmmin}\Big|_{R_p=\infty} = \frac{100}{100 + \frac{5M}{6000}} \cdot 30 = 3{,}21\,V \quad \ldots 5$$

c.)



$$I_{LED_{max}} = \frac{V_{OPmax}}{R_2 + \frac{R_3}{\beta_3 + 1}} = \frac{10{,}26}{470 + \frac{18k}{121}} = 16{,}5\,mA$$

$$R_{xmin} = R(I_{LEDmax}) = 990 \cdot \frac{1}{16{,}5m}^{0{,}8} = 26{,}4k\Omega$$

$$V_{Pmmax}\Big|_{R_p=8\Omega} = 30\,\frac{100 \| 8}{100 \| 8 + \frac{26{,}4k}{6000}} = 18{,}8\,V$$

$\ldots 5$