ISPITNI ZADACI
IZ ELEKTRONIKE 2

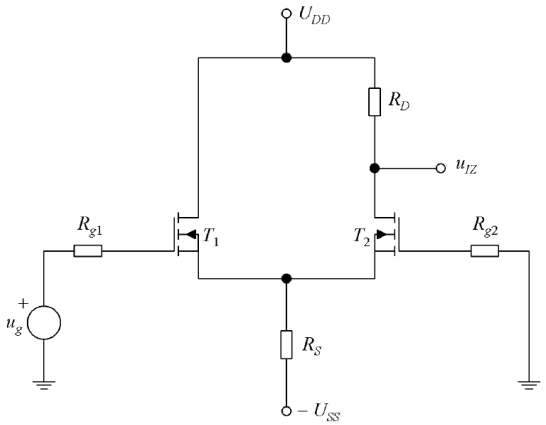
* Ponavljaju se tipovi zadataka, ali budu druge vrijednosti zadane.
Ako sam nešto krivo nije namjerno.

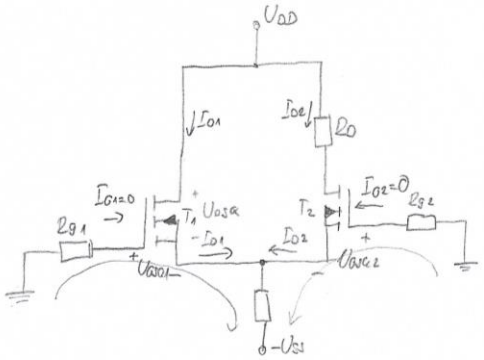
1. DIFERENCIJSKA POJAČALA

MI 2014, 2016, 2018, 2019

Za diferencijsko pojačalo sa slike zadano je $U_{DD} = U_{SS} = 15\ \text{V}$, $R_{g1} = R_{g2} = 500\ \Omega$, $R_D = 3\ \text{k}\Omega$ i $R_S = 6\ \text{k}\Omega$. Tranzistori T_1 i T_2 imaju jednake parametre $K = 2\ \text{mA/V}^2$ i $U_{GS0} = 2\ \text{V}$. Zanemarite porast struja odvoda u području zasićenja.

a) Izračunati struje I_{DQ} i napone U_{DSQ} za oba tranzistora u statičkoj radnoj točki.
b) Odrediti naponsko pojačanje zajedničkog i diferencijskog signala $A_{Vz} = u_{iz}/u_z$ i $A_{Vd} = u_{iz}/u_d$, te faktro potiskivanja ρ.
c) Izračunati izmjenični izlazni napon u_{iz} ako je napon $u_g = 200\sin(\omega t)\ \text{mV}$





$$I_{D1} = \frac{U_{SS} - U_{DSQ1}}{2R_S} = \frac{K}{2}(U_{GSQ1} - U_{GS0})^2$$

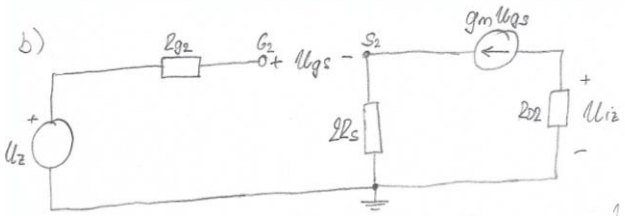
$$I_{D2} = I_{D1}$$

$$U_{DD} + U_{SS} - 2R_S I_{DQ1} = U_{DSQ1}$$

$$U_{DD} + U_{SS} - 2R_S I_{DQ2} - R_D I_{DQ2} = U_{DSQ2}$$

$$g_m = \frac{\partial i_D}{\partial u_{GS}}\Big|_Q = K(U_{GSQ} - U_{GS0}) = \ldots \qquad r_d \to \infty$$

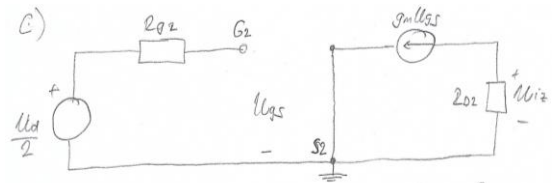
b)



$$A_{Vz} = \frac{u_{iz}}{u_z} \qquad u_{iz} = -g_m u_{gs} R_D \qquad u_z = u_{gs} + g_m u_{gs} \cdot 2R_S$$

$$A_{Vz} = \frac{-g_m R_D}{1 + 2g_m R_S}$$

c)



$$A_{Vd} = \frac{u_{iz}}{u_d} \qquad u_{iz} = -g_m u_{gs} R_D \qquad \frac{u_d}{2} = u_{gs}$$

$$A_{VD} = \frac{1}{2}\frac{-g_m R_D}{1} = \frac{-g_m R_D}{2}$$

$$\rho = \frac{|A_{Vd}|}{|A_{Vz}|}$$

$u_{g1} = 200\sin(\omega t)\ \text{mV}$ $\qquad u_{g2} = 0$

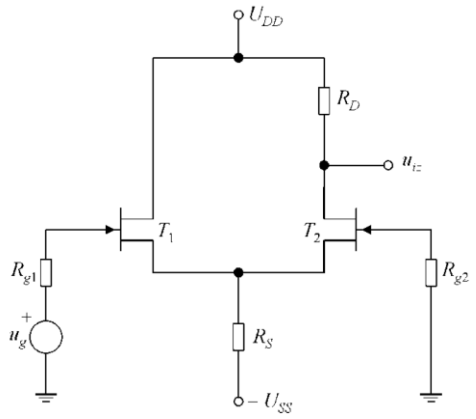
$U_{zm} = \frac{U_{gm} + 0}{2}$ $\qquad U_{dm} = 0 - U_{gm}$

$U_{izm} = A_{Vz} U_{zm} + A_{Vd} U_{dm}$ $\qquad u_{iz} = U_{izm}\sin(\omega t)$

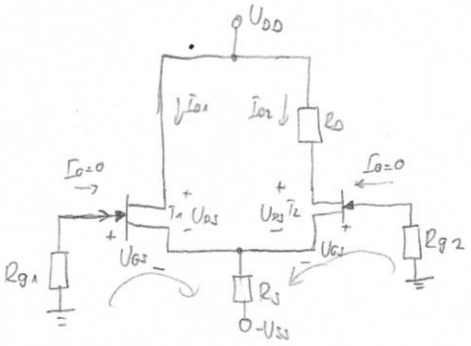
ZI 2020 *JIR 2017,2018* *LJIR 2018, 2019* *ZIR 2017*

Za diferencijsko pojačalo sa slike zadano je $U_{DD} = U_{SS} = 10\ \text{V}$, $R_{g1} = R_{g2} = 1\ \text{k}\Omega$, $R_D = 1\ \text{k}\Omega$ i $R_S = 3\ \text{k}\Omega$. Tranzistori T_1 i T_2 imaju jednake parametre $I_{DSS} = 8\ \text{mA}$ i $U_P = -4\ \text{V}$. Zanemarite porast struja odvoda u području zasićenja.

a) Izračunati struje I_{DQ} i napone U_{DSQ} za oba tranzistora u statičkoj radnoj točki.
b) Odrediti naponsko pojačanje zajedničkog i diferencijskog signala $A_{Vz} = u_{iz}/u_z$ i $A_{Vd} = u_{iz}/u_d$, te faktro potiskivanja ρ.
c) Izračunati izmjenični izlazni napon u_{iz} ako je napon $u_g = 150\sin(\omega t)\ \text{mV}$



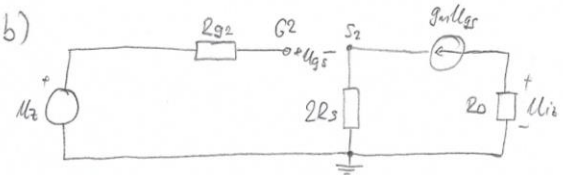
a)



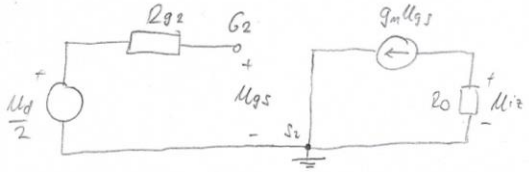
$$U_{GSQ} = U_{SS} - 2R_S I_{DQ}$$
$$I_{DQ} = I_{DSS}\left(1 - \frac{U_{GSQ}}{U_P}\right)^2$$

$$U_{DSQ1} = U_{DD} + U_{SS} - 2R_S I_{DQ1}$$
$$U_{DSQ2} = U_{DD} + U_{SS} - 2R_S I_{DQ2} - I_{DQ2} R_D$$

b)



$$u_{iz} = -g_m u_{gs} R_D$$
$$u_z = u_{gs} + g_m u_{gs} 2R_S$$
$$A_{Vz} = \frac{u_{iz}}{u_z} = \frac{-g_m R_D}{1 + g_m 2R_S}$$



$$A_{Vd} = -\frac{g_m R_D}{2}$$

$$\rho = \frac{|A_{Vd}|}{|A_{Vz}|}$$

c) $u_{g1} = 150\sin(\omega t)\ \text{mV}$, $u_{g2} = 0$

$$U_{zm} = \frac{U_{gm1} + U_{gm2}}{2} \qquad U_{dm} = U_{gm2} - U_{gm1}$$

$$U_{izm} = U_{zm} \cdot A_{Vz} + U_{dm} \cdot A_{Vd}$$

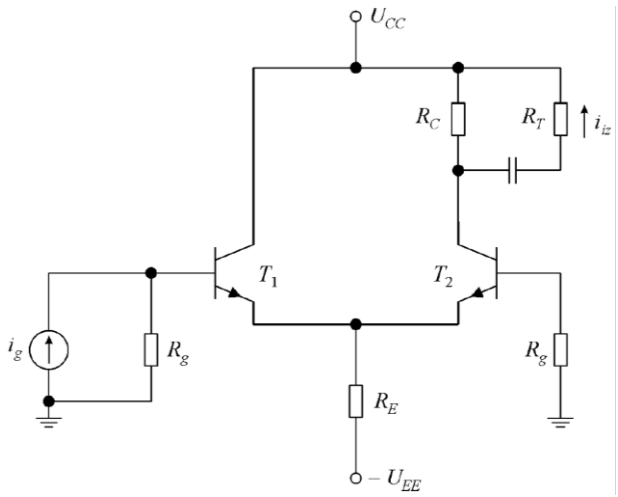
$\rightarrow u_{iz} = U_{izm}\sin(\omega t)$

LJIR 2014, 2017 *DIR 2018*

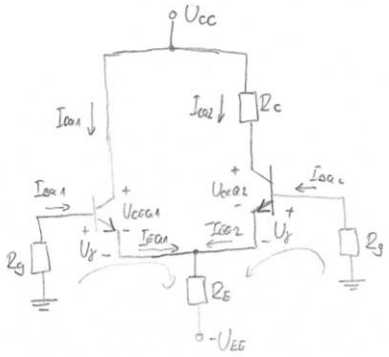
Za diferencijsko pojačalo sa slike zadano je $U_{CC} = U_{EE} = 12$ V, $R_g = 5$ kΩ, $R_C = 500\ \Omega$ i $R_E = 5$ kΩ i $R_T = 100\ \Omega$. Tranzistori T_1 i T_2 imaju jednake parametre $\beta \approx h_{fe} = 100$ i $U_\gamma = 0{,}7$ V. Zanemarite porast struja kolektora u NAP. Naponski ekvivalent temperature $U_T = 25$ mV.

a) Izračunati struje I_{CQ} i napone U_{CEQ} za oba tranzistora u statičkoj radnoj točki.
b) Odrediti naponsko pojačanje zajedničkog i diferencijskog signala $A_{Iz} = i_{iz}/i_z$ i $A_{Id} = i_{iz}/i_d$, te faktro potiskivanja ρ.

c) Izračunati izlaznu struju ako je struja $i_g = 10\sin(\omega t)$ µA



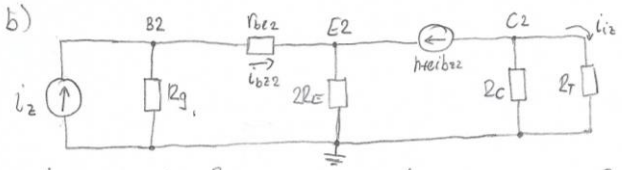
a)



$$I_{BQ} = I_{BQ1} = I_{BQ2} = \frac{U_{EE} - U_\gamma}{R_g + 2(1+\beta)R_E} \quad \Rightarrow I_{CQ} = \beta \cdot I_{BQ}$$

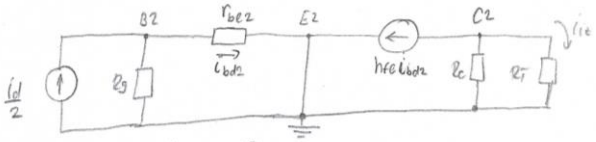
$$U_{CEQ1} = U_{CC} + U_{EE} - 2R_E I_{CQ}$$
$$U_{CEQ2} = U_{CC} + U_{EE} - 2R_E I_{CQ} - R_C I_{CQ}$$
$$r_{be1} = r_{be2} = \frac{U_T}{I_{BQ}}$$

b)



$$i_{iz} = -h_{fe}\, i_{b2}\, \frac{R_C}{R_C + R_T}$$
$$i_{b2} = \frac{R_g}{R_g + r_{be} + (1+h_{fe})2R_E} \cdot i_z$$

$$\Rightarrow A_{Iz} = -h_{fe}\, \frac{R_C}{R_C + R_T} \cdot \frac{R_g}{R_g + r_{be} + (1+h_{fe})2R_E}$$



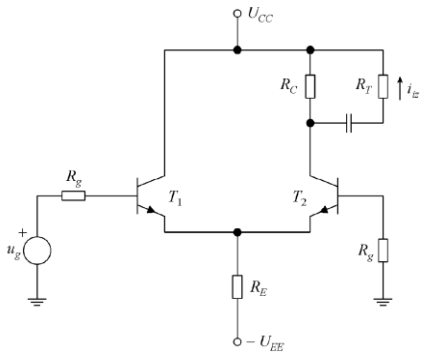
$$i_{iz} = -h_{fe}\, i_{b2}\, \frac{R_C}{R_C + R_T}$$
$$i_{b2} = \frac{R_g}{R_g + r_{be}}\, \frac{i_d}{2}$$

$$\Rightarrow A_{Id} = -\frac{1}{2} h_{fe}\, \frac{R_C}{R_C + R_T} \cdot \frac{R_g}{R_S + r_{be}}$$

c) $U_{gm1} = 20 \rightarrow I_{gm1} = \frac{U_{gm}}{R_g}$, $I_{gm2} = 0$

$$I_{zm} = \frac{I_{gm}}{2} \qquad I_{dm} = -I_{gm1}$$
$$I_{iz} = I_{zm} A_{Iz} + I_{dm} A_{Id}$$

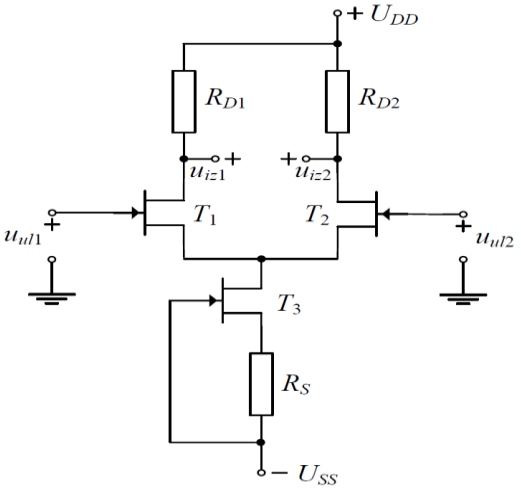
MI 2015 *LJIR 2020* *ZIR 2013, 2014, 2018*

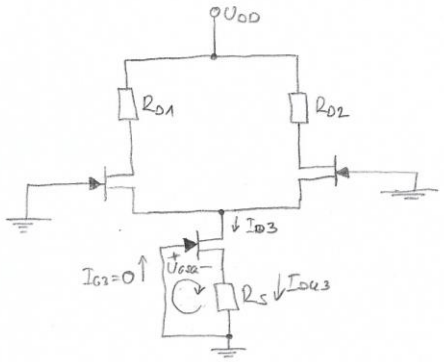
	isti zadatak kao prošli samo treba generator izmjeničnog napona pretvoriti u generator izmjenične struje

Za pojačalo sa slike zadano je $U_{DD} = U_{SS} = 3\ \text{V}$, $R_{D1} = R_{D2} = 1\ \text{k}\Omega$, i $R_S = 500\ \Omega$. Tranzistori T_1, T_2 i T_3 imaju jednake parametre $I_{DSS} = 2\ \text{mA}$ i $U_P = -1\ \text{V}$. Zanemarite porast struja odvoda u području zasićenja.

Uz izlazni diferencijski napon $u_{iz} = u_{iz2} - u_{iz1}$ odrediti zajedničko $A_{Vz} = u_{iz}/u_z$ i diferencijsko pojačanje $A_{Vd} = u_{iz}/u_d$, te faktor potiskivanja ρ.

Izračunati izlazni napon uz sinusni izmjenični signal na ulazu amplitude $u_{ul1} = 15\sin(\omega t)\ \text{mV}$ i $u_{ul2} = 5\sin(\omega t)\ \text{mV}$.





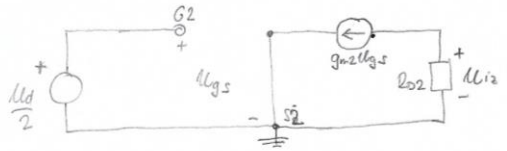
$$U_{GSQ3} = -I_{DQ3} R_S$$
$$I_{DQ3} = I_{DSS}\left(1 - \frac{U_{GSQ3}}{U_P}\right)^2$$

$$U_{GSQ3}^2 + \left(\frac{U_P^2}{I_{DSS} R_S} - 2U_P\right) U_{GSQ3} + U_P^2 = 0$$

$$I_{DQ1} = I_{DQ2} = \frac{I_{DQ3}}{2}$$

$$U_{GSQ1,2} = U_P\left(1 - \sqrt{\frac{I_{DQ1,2}}{I_{DSS}}}\right)$$

$$g_{m1,2,3} = \frac{\partial i_D}{\partial u_{GS}}\Big|_Q = -\frac{2\,I_{DSS}}{U_P}\left(1 - \frac{U_{GSQ1,2}}{U_P}\right) \qquad r_{d1,2} \to \infty$$



$$u_{iz} = -g_m u_{gs} R_{D2}$$
$$\frac{u_d}{2} = u_{gs}$$
$$A_{vd} = \frac{u_{iz}}{u_d} = -\frac{g_m R_{D2}}{2}$$

$$\rho = \frac{|A_{vd}|}{|A_{vz}|}$$

$$U_{dm} = U_{ul2} - U_{ul1}$$

$$U_{izm} = \frac{1}{2} U_{dm} \cdot A_{vd}$$

simetričan izlaz

$$\rightarrow u_{iz} = U_{izm}\sin(\omega t)$$

za A_{vz} nisam siguran jel 0 zbog simetričnosti kao u primjeru i zzv ili se mora računati R_{iz3}

2. POJAČALA SNAGE

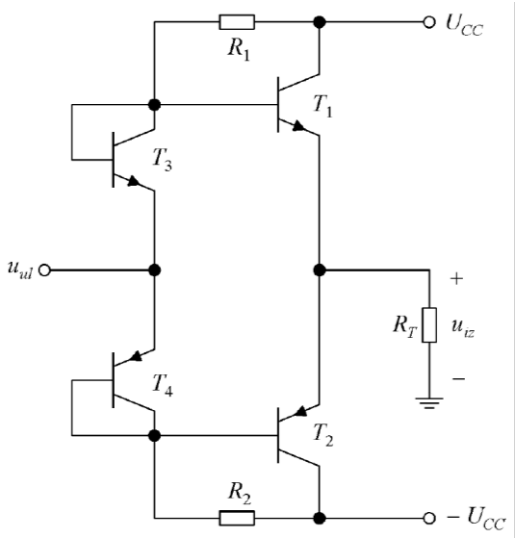
Izlazno pojačalo na slici koje radi s naponom napajanja $U_{DD} = 10$ V treba predati srednju snagu od 3 W trošilu otpora od 4 Ω. Tranzistori su jednakih površina i imaju jednake parametre $\beta = 80$ i $U_\gamma = 0{,}7$ V. Odrediti:

a) najveću moguću amplitudu izlaznog napona

b) otpore otpornika za amplitudu $R_1 = R_2$

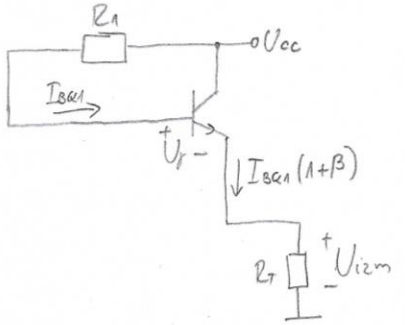
c) potrošnju snage na tranzistoru T_3 u statičkom režimu rada

d) najveću i najmanju potrošnju snage na tranzistorima T_1 i T_2



a) $P_{RT} = \frac{U_{izm}^2}{2R_T} \Rightarrow U_{izm} = \sqrt{2P_{RT}R_T}$

b)



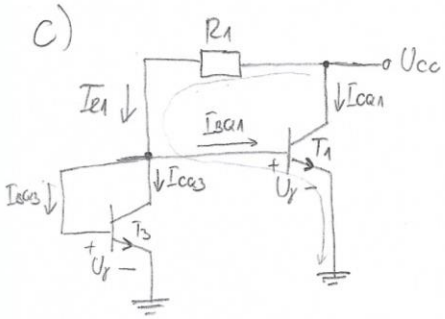
$U_{CC} - U_\gamma - R_1 I_{BQ1} - R_T(1+\beta) I_{BQ1}$

$I_{BQ1,max} = \frac{U_{CC} - U_\gamma}{R_1 + (1+\beta)R_T}$

$U_{izm} = I_{BQ1,max}(1+\beta)R_T$

$U_{izm} = (U_{CC} - U_\gamma)\frac{(1+\beta)R_T}{R_1 + (1+\beta)R_T} \rightarrow R_1$

c)



$I_{E1} = \frac{U_{CC} - U_\gamma}{R_1}$

$I_{E1} = I_{BQ1} + (1+\beta) I_{BQ3} = \frac{2+\beta}{\beta} I_{CQ3} \rightarrow I_{CQ3} = I_{CQ1} = I_{CQ2}$

$P_{T3} = U_\gamma (I_{BQ3} + I_{CQ3})$

d) $P_{T1} = U_{CC} I_{CQ1} + \frac{P_{CC} - P_{RT}}{2} = U_{CC} I_{CQ1} + U_{CC}\frac{I_{Cm}}{\pi} - R_T\frac{I_{Cm}^2}{4}$

za $I_{Cm} = 0 \rightarrow P_{T1} = P_{T1,min} = U_{CC} I_{CQ1}$

$\frac{\partial P_{T1}}{\partial I_{Cm}} = \frac{U_{CC}}{\pi} - R_T\frac{I_{Cm}}{2} = 0 \rightarrow I_{Cm}|_{P_{T1,max}} = \frac{2}{\pi}\frac{U_{CC}}{R_T}$

za $I_{Cm} = \frac{2}{\pi}\frac{U_{CC}}{R_T} \rightarrow P_{T1} = P_{T1,max} = U_{CC} I_{CQ1} + \frac{U_{CC}^2}{\pi^2 R_T}$

MI 2018 zzv zad3

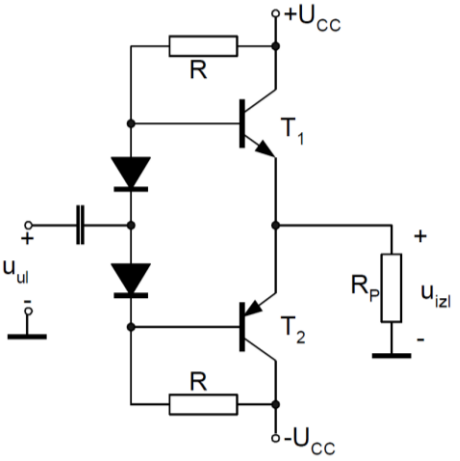
Za pojačalo snage na slici treba izračunati:

a) Disipaciju na otporniku R, diodi i tranzistoru T_2 kada nije priključen ulazni signal

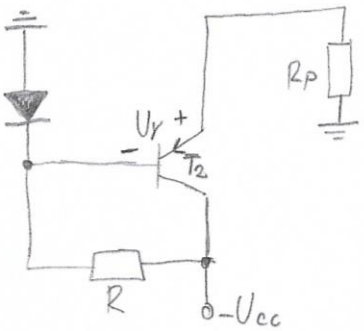
b) Maksimalni iznos izlaznog napona

c) Maksimalnu srednju disipaciju na otporu R_P

Zadano je: $U_{CC} = 12\ \text{V}$, $R = 560\ \Omega$, $R_P = 4\ \Omega$, $\beta = 150$



a)



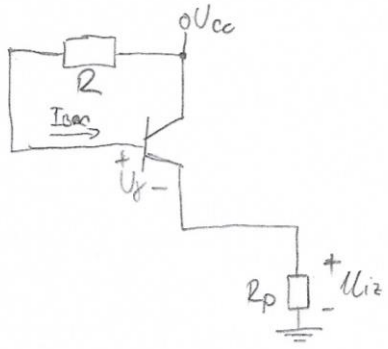
$$I_{RQ} = \frac{-U_{CC} + U_\gamma}{R_1} \qquad P_R = I_{RQ}^2 \cdot R_1$$

$$P_D = U_D \cdot I_{RQ} \quad (U_D \approx -0{,}7\ \text{V})$$

u stat prilikama $U_{CEQ} = U_{CC}$, $I_{CQ} \approx I_{EQ}$

$$P_{T1} = U_{CEQ} I_{CQ} = -U_{CC} I_{RQ}$$

b)



$$U_{CC} - R I_{Bm} - U_\gamma - (1+\beta) I_{Bm} R_P = 0$$

$$I_{Bm} = \frac{U_{CC} - U_\gamma}{R + (1+\beta) R_P}$$

$$U_{iz,max} = (1+\beta) I_{Bm} R_P$$

c) $$P_{Rp,max} = \frac{U_{iz,max}^2}{2R_P}$$

3. KASKADNA POJAČALA

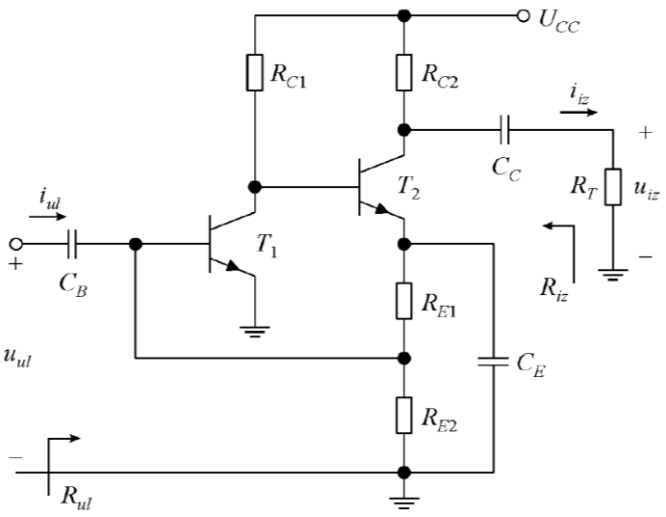
MI 2014, 2016, 2017, 2018, 2019

Za pojačalo sa slike zadano je:
$U_{CC} = 15$ V, $R_{C1} = 4$ kΩ, $R_{C2} = 3$ kΩ i $R_{E1} = 2$ kΩ, $R_{E2} = 350$ Ω i $R_T = 1$ kΩ. Parametri oba tranzistora su $\beta \approx h_{fe} = 100$ i $U_\gamma = 0{,}7$ V. Zanemarite porast struja kolektora u NAP. Naponski ekvivalent temperature $U_T = 25$ mV.

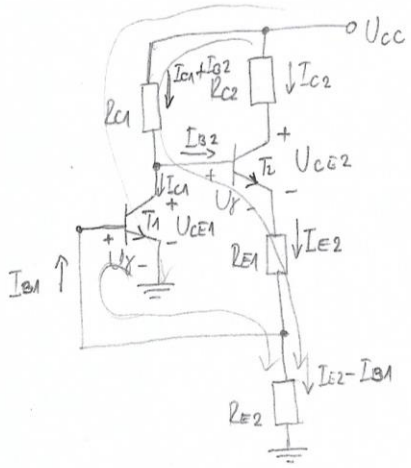
a) Izračunati struje I_{CQ} i napone U_{CEQ} za oba tranzistora u statičkoj radnoj točki.

b) Nacrtati nadomjesnu shemu pojačala za dinamičku analizu na srednjim frekvencijama, te odrediti pojačanja $A_V = u_{iz}/u_{ul}$ i $A_I = i_{iz}/i_{ul}$

c) Izračunati ulazni i izlazni otpor R_{ul} i R_{iz}.



a)



$$I_{E2} \approx \frac{U_\gamma}{R_{E2}} \rightarrow I_{CQ2}$$

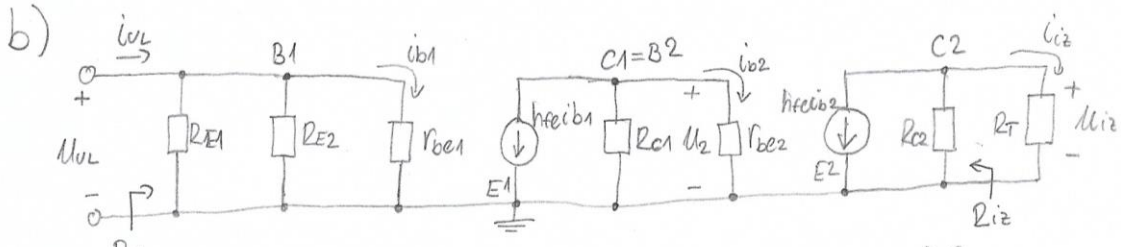
$$U_{CC} = (I_{CQ1}+I_{BQ2})R_{C1} + U_\gamma + I_{EQ2}R_{E1} + (I_{EQ2}-I_{BQ1})R_{E2} \rightarrow I_{BQ1} \rightarrow I_{CQ1}$$

$$U_{CEQ1} = U_{CC} - (I_{CQ1}+I_{BQ2})R_{C1}$$

$$U_{CEQ2} = U_{CC} - I_{CQ2}R_{C2} - I_{EQ2}R_{E1} - (I_{EQ2}-I_{BQ1})R_{E2}$$
$$\approx U_{CC} - I_{CQ2}(R_{C2}+R_{E1}+R_{E2})$$

$$r_{be1} = \frac{U_T}{I_{BQ1}}, \quad r_{be2} = \frac{U_T}{I_{BQ2}}$$

b)



$$A_V = \frac{u_{iz}}{u_{ul}} = \underbrace{\frac{u_{iz}}{u_2}}_{A_{V2}} \cdot \underbrace{\frac{u_2}{u_{ul}}}_{A_{V1}}$$

$$u_{iz} = -h_{fe}i_{b2}(R_{C2}\|R_T) \Rightarrow A_{V2} = -h_{fe}\frac{(R_{C2}\|R_T)}{r_{be2}}$$
$$u_2 = i_{b2}r_{be2}$$

$$u_2 = -h_{fe}i_{b1}(R_{C1}\|r_{be2}) \Rightarrow A_{V1} = -h_{fe}\frac{(R_{C1}\|r_{be2})}{r_{be1}}$$
$$u_{ul} = r_{be1}i_{b1}$$

c) $R_{ul} = R_{E1}\|R_{E2}\|r_{be1}$

$$A_I = \frac{i_{iz}}{i_{ul}} = \frac{\frac{u_{iz}}{R_T}}{\frac{u_{ul}}{R_{ul}}} = A_V\frac{R_{ul}}{R_T}$$

$R_{iz} = R_{C2}$

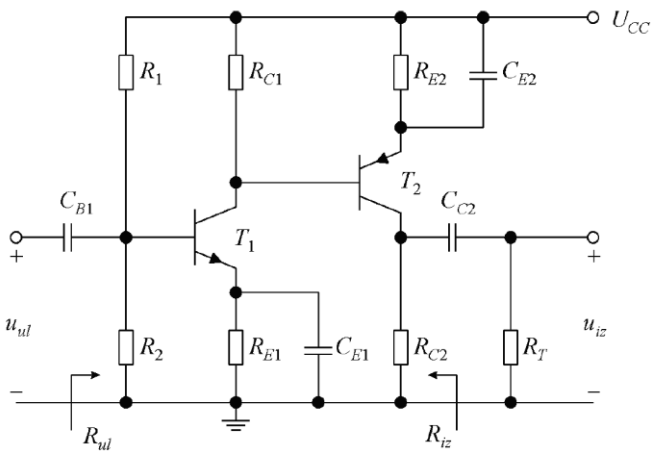
MI 2015

Za pojačalo sa slike zadano je:
$U_{CC} = 15$ V, $R_1 =$ Ω, $R_2 =$ Ω, $R_{C1} =$ kΩ, $R_{C2} =$ kΩ, $R_{E1} = 2$ kΩ, $R_{E2} = 350$ Ω i $R_T = 1$ kΩ. Parametri oba tranzistora su $\beta \approx h_{fe} = 100$ i $U_\gamma = 0{,}7$ V. Zanemarite porast struja kolektora u NAP. Naponski ekvivalent temperature $U_T = 25$ mV.

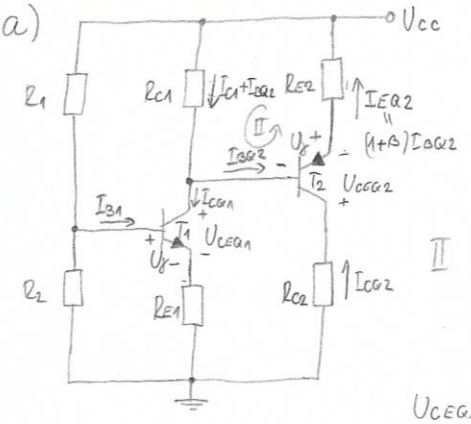
a) Izračunati struje I_{CQ} i napone U_{CEQ} za oba tranzistora u statičkoj radnoj točki.

b) Nacrtati nadomjesnu shemu pojačala za dinamičku analizu na srednjim frekvencijama, te odrediti pojačanja $A_V = u_{iz}/u_{ul}$ i $A_I = i_{iz}/i_{ul}$

c) Izračunati ulazni i izlazni otpor R_{ul} i R_{iz}.



a)



$$U_{BB1} = \frac{R_2}{R_1+R_2} U_{CC} \qquad R_{B1} = R_1 \| R_2$$

$$I_{BQ1} = \frac{U_{BB} - U_\gamma}{R_B + (1+\beta) R_{E1}} \qquad I_{CQ1} = \beta I_{BQ1}$$

$$\text{II} \quad (I_{CQ1} + I_{BQ2}) R_{C1} - U_\gamma + (1+\beta) I_{BQ2} = 0$$

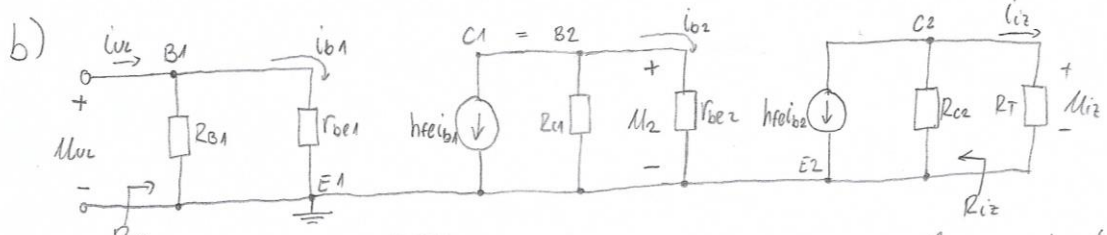
$$I_{BQ2} = -\frac{I_{CQ1} R_{C1} - U_\gamma}{R_{C1} + (1+\beta) R_{E2}}$$

$$U_{CEQ1} = V_{CC} - R_{C1}(I_{CQ1} + I_{BQ2}) - R_{E1}(1+\beta) I_{BQ1}$$

$$U_{CEQ2} = -V_{CC} - R_{E2}(1+\beta) I_{BQ2} - R_{C2} I_{CQ2}$$

$$r_{be1} = \frac{U_T}{I_{BQ1}} \quad , \quad r_{be2} = \frac{U_T}{-I_{BQ2}}$$

b)



$$A_V = \frac{u_{iz}}{u_{ul}} = \frac{u_{iz}}{u_2} \cdot \frac{u_2}{u_{ul}} \qquad A_{V2} \quad A_{V1}$$

$$u_2 = i_{b2} \cdot r_{be2}$$
$$u_{iz} = -h_{fe} i_{b2} (R_{C2} \| R_T)$$
$$A_{V2} = -\frac{h_{fe}(R_{C2} \| R_T)}{r_{be2}}$$

$$u_{ul} = i_{b1} \cdot r_{be1}$$
$$u_2 = -h_{fe} i_{b1} (R_{C1} \| r_{be2})$$
$$A_{V1} = -\frac{h_{fe}(R_{C1} \| r_{be2})}{r_{be1}}$$

$$A_I = \frac{i_{iz}}{i_{ul}} = \frac{\frac{u_{iz}}{R_T}}{\frac{u_{ul}}{R_{ul}}} = A_V \frac{R_{ul}}{R_T}$$

c) $R_{ul} = R_{B1} \| r_{be1}$

$R_{iz} = R_{C2}$

4. FREKVENCIJSKA ANALIZA

MI 2014, 2016, 2019 *DIR 2018*

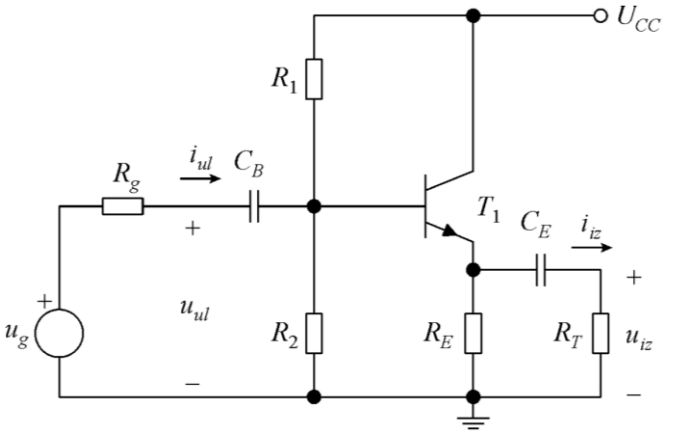
Za pojačalo sa slike zadano je:
$U_{CC} = 12$ V, $R_g = 500\ \Omega$, $C_B = 1$ µF $R_1 = 120$ kΩ i $R_2 = 200$ kΩ, $R_E = 4{,}5\ \Omega$, $C_E = 5$ µF i $R_T = 500\ \Omega$.
Parametri oba tranzistora su $\beta \approx h_{fe} = 100$ i $U_\gamma = 0{,}7$ V.
Zanemariti serijski otpor baze $r_{bb'}$ i porast struje kolektora s naponom u_{CE} u NAP. Naponski ekvivalent temperature $U_T = 25$ mV.

a) Izračunati struje I_{CQ} i napone U_{CEQ} za oba tranzistora u statičkoj radnoj točki.

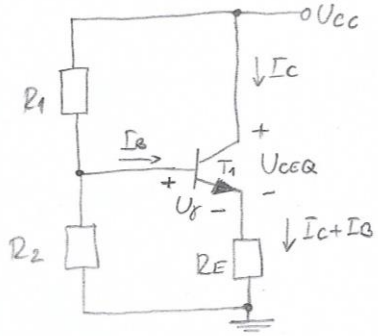
b) Nacrtati nadomjesnu shemu pojačala za dinamičku niskofrekvencijsku analizu

c) Izračunati pojačanje $A_{Vg} = U_{iz}/U_g$ na srednjim frekvencijama

d) Izračunati donju graničnu frekvenciju pojačanja A_{Vg}.



a)



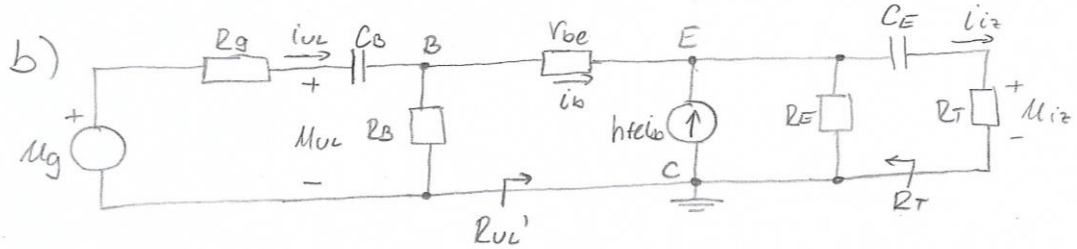
$$U_{BB} = \frac{R_2}{R_1 + R_2} U_{CC} \qquad R_B = R_1 \| R_2$$

$$I_{BQ} = \frac{U_{BB} - U_\gamma}{R_B + (1+\beta) R_E} \qquad I_{CQ} = \beta I_{BQ}$$

$$U_{CEQ} = U_{CC} - R_E (1+\beta) I_{BQ}$$

$$r_{be} = \frac{U_T}{I_{BQ}}$$

b)



c) $$A_{vgo} = \frac{u_{iz}}{u_g} = \boxed{\frac{u_{iz}}{u_{ul}}}_{A_{v2}} \cdot \boxed{\frac{u_{ul}}{u_g}}_{A_{v1}}$$

$$u_{iz} = (1+h_{fe})(R_E \| R_T)\, i_b$$

$$u_{ul} = i_b r_{be} + (1+h_{fe})(R_E \| R_T)\, i_b$$

$$A_{v2} = \frac{(1+h_{fe})(R_E \| R_T)}{r_{be} + (1+h_{fe})(R_E \| R_T)}$$

$$u_{ul} = \frac{R_B \| R_{ul}'}{R_B \| R_{ul}' + R_g} u_g \quad , \quad R_{ul}' = r_{be} + (1+h_{fe})(R_E \| R_T)$$

d) $$\tau_B = C_B (R_g + R_B \| R_{ul}') \quad , \quad \omega_B = \frac{1}{\tau_B}$$

$$\tau_E = \left(\frac{r_{be} + R_B \| R_g}{1+h_{fe}} \,\middle\|\, R_E + R_T \right) C_E \quad , \quad \omega_E = \frac{1}{\tau_E}$$

$$\omega_d = \max\{\omega_B, \omega_E\} \quad , \quad f_d = \frac{\omega_d}{2\pi}$$

MI 2015 ZI 2017 ZIR 2013, 2018 LJIR 2014, 2017

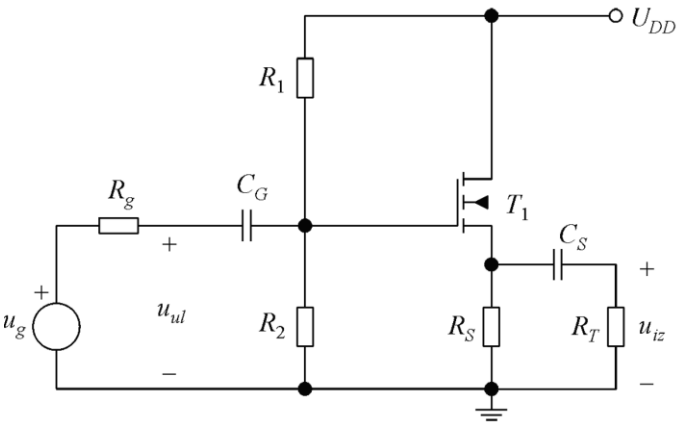
Za pojačalo sa slike zadano je:
$U_{DD} = 12$ V, $R_g = 1$ kΩ, $C_G = 20$ nF, $R_1 = 3$ MΩ, $R_2 = 6$ MΩ, $R_S = 1$ kΩ, $C_S = 5$ μF i $R_T = 1$ kΩ.
Parametri FET-a su $K = 2{,}5\ \text{mA/V}^2$ i $U_{GS0} = 1$ V.
Zanemariti porast struje odvoda s naponom u_{DS} u području zasićenja.

a) Izračunati struju I_{DQ} i napone U_{GSQ} i U_{DSQ} u statičkoj radnoj točki.

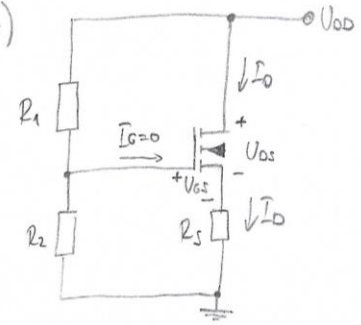
b) Nacrtati nadomjesnu shemu pojačala za dinamičku niskofrekvencijsku analizu

c) te odrediti pojačanje $A_{Vg} = U_{iz}/U_g$ na srednjim frekvencijama

d) Izračunati donju graničnu frekvenciju pojačanja A_{Vg}.



a)



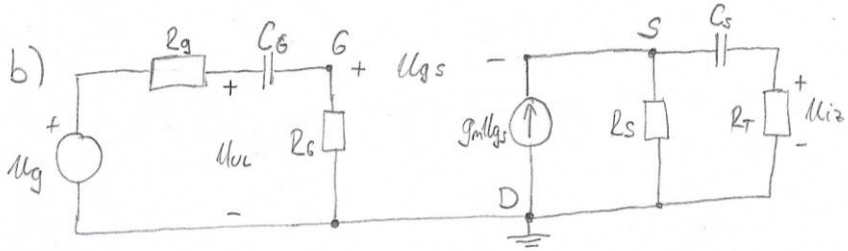
$$U_{GG} = \frac{R_2}{R_1+R_2}U_{DD} \qquad R_G = R_1 \| R_2$$

$$\left.\begin{aligned} U_{GG} &= U_{GSQ} + R_S I_{DQ} \\ I_{DQ} &= \frac{K}{2}(U_{GSQ} - U_{GS0})^2 \end{aligned}\right\} \; U_{GSQ}^2 + \left(\frac{2}{R_S K} - 2U_{GS0}\right)U_{GSQ} + U_{GS0}^2 - \frac{2U_{GG}}{R_S K} = 0$$

$$U_{DSQ} = U_{DD} - R_S I_{DQ}$$

$$g_m = K(U_{GSQ} - U_{GS0})$$

b)



c) $$A_{vgo} = \frac{u_{iz}}{u_g} = \underbrace{\frac{u_{iz}}{u_{gs}}}_{A_1} \cdot \underbrace{\frac{u_{gs}}{u_{ul}}}_{A_2} \cdot \underbrace{\frac{u_{ul}}{u_g}}_{A_3} = \frac{g_m(R_S \| R_T)}{1+g_m(R_S \| R_T)} \cdot \frac{R_G}{R_g+R_G}$$

$$u_{iz} = g_m u_{gs}(R_S \| R_T) \longrightarrow A_1 = \frac{u_{iz}}{u_{gs}} = g_m(R_S \| R_T)$$

$$u_{ul} = u_{gs} + u_{iz} \longrightarrow A_2 = \frac{u_{gs}}{u_{ul}} = \frac{1}{1+g_m(R_S \| R_T)}$$

$$u_{ul} = \frac{R_G}{R_g+R_G}u_g$$

d) $$\tau_G = (R_g + R_G)C_G \quad , \quad \omega_g = \frac{1}{\tau_G}$$

$$\tau_S = \left(R_S \| \frac{1}{g_m} + R_T\right)C_S \quad , \quad \omega_S = \frac{1}{\tau_S}$$

$$\omega_d = \max\{\omega_G, \omega_S\} \quad , \quad f_d = \frac{\omega_d}{2\pi}$$

ZI 2020 *ZIR 2017* *LJIR 2018, 2019* *JIR 2017, 2018*

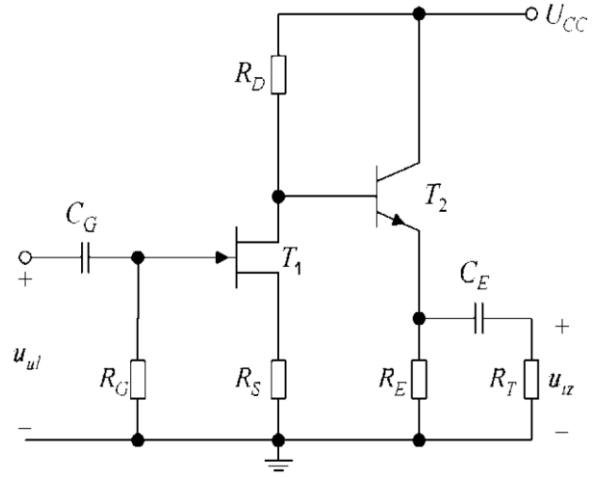
Za pojačalo sa slike zadano je:
$U_{CC} = 15$ V, $R_G = 100$ kΩ, $R_D = 1$ kΩ, $R_E = 4$ kΩ, $R_T = 1$ kΩ, $C_G = 200$ nF i $C_E = 2$ μF.
Parametri oba tranzistora su $I_{DSS} = 32$ mA, $U_P = -2$ V, $\beta \approx h_{fe} = 100$ i $U_\gamma = 0{,}7$ V. Zanemariti serijski otpor baze $r_{bb'}$ i poraste struje odvoda s naponom u_{DS} u području zasićenja i struje kolektora s naponom u_{CE} u NAP. Naponski ekvivalent temperature $U_T = 25$ mV.

a) Odrediti otpor R_S s kojim će se postići struja $I_{DQ} = 8$ mA, te izračunati struju I_{CQ} i napon U_{DSQ} i U_{CEQ} u statičkoj radnoj točki.

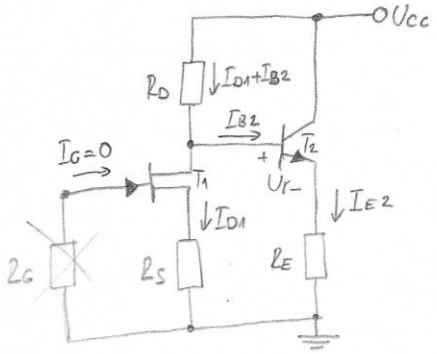
b) Nacrtati nadomjesnu shemu pojačala za dinamičku niskofrekvencijsku analizu

c) Izračunati pojačanje $A_V = U_{iz}/U_{ul}$ na srednjim frekvencijama

d) Izračunati donju graničnu frekvenciju pojačanja A_V.



a)



$$I_{DQ1} = I_{DSS}\left(1 - \frac{U_{GSQ1}}{U_P}\right)^2 \rightarrow U_{GSQ1}$$

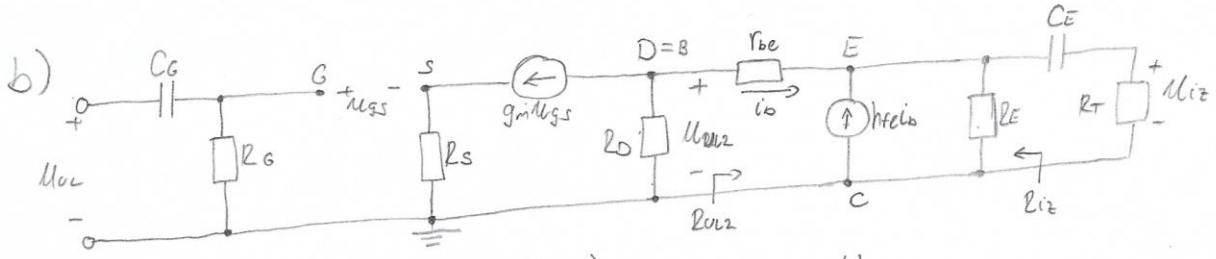
$$R_S = -\frac{U_{GSQ}}{I_{DQ1}}$$

$$U_{DSQ} \approx U_{CC} - I_{DQ1}(R_D + R_S)$$

$$I_{BQ2} = \frac{U_{CC} - U_\gamma - R_D I_{DQ1}}{R_D + (1+\beta) R_S} \rightarrow I_{CQ2}$$

$$U_{CEQ2} = U_{CC} - (1+\beta) I_{BQ2} R_E$$

b)



$$g_m = \frac{\partial i_D}{\partial u_{GS}}\Big|_Q = -\frac{2 I_{DSS}}{U_P}\left(1 - \frac{U_{GSQ}}{U_P}\right) \qquad r_{be} = \frac{U_T}{I_{BQ}}$$

c)

$$A_{V0} = \frac{u_{iz}}{u_{ul}} = \underbrace{\frac{u_{iz}}{u_{DS2}}}_{A_{V2}} \cdot \underbrace{\frac{u_{DS2}}{u_{ul}}}_{A_{V1}} \qquad A_{V2} = \frac{u_{iz}}{u_{DS2}} = \frac{i_b(1+h_{fe})(R_E \| R_T)}{i_b r_{be} + i_b(1+h_{fe})(R_E \| R_T)}$$

$$A_{V1} = \frac{-g_m u_{gs}(R_D \| R_{DS2})}{u_{gs} + g_m u_{gs} R_S}$$

$$A_{V0} = -g_m \frac{R_D \| R_{DS2}}{1 + g_m R_S} \cdot \frac{(1+h_{fe})(R_E \| R_T)}{r_{be} + (1+h_{fe})(R_E \| R_T)}$$

d)

$$\tau_G = C_G R_G \rightarrow \omega_G = \frac{1}{\tau_G}$$

$$\tau_E = C_E\left(R_T + R_E \| \frac{r_{be} + R_D}{1+h_{fe}}\right) \rightarrow \omega_E = \frac{1}{\tau_E}$$

nisam siguran

ZI 2012, 2014, 2016, 2018, 2020 *ZIR 2013, 2017, 2018* *LJIR 2014, 2017* *JIR 2017, 2018*

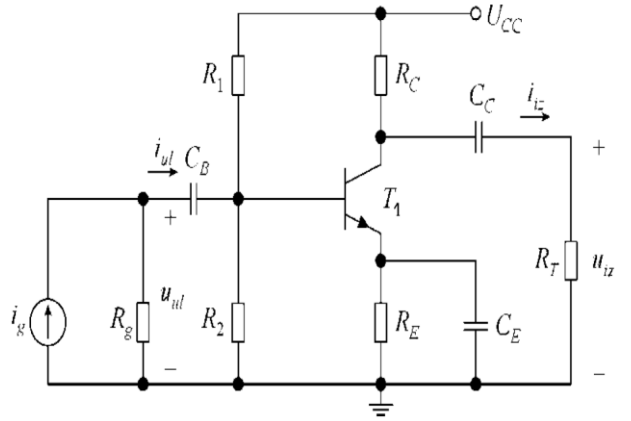
Za pojačalo sa slike zadano je:
$U_{CC} = 12$ V, $R_g = 5$ kΩ, $C_B = 2$ μF, $R_1 = 40$ kΩ, $R_2 = 10$ kΩ, $R_C = 2$ kΩ, $R_E = 500$ Ω, $R_T = 500$ kΩ, $C_C = 2$ μF i $C_E = 50$ μF.
Parametri oba tranzistora su $\beta \approx h_{fe} = 100$, $U_\gamma = 0{,}7$ V, $r_{bb'} = 50$ Ω, $C_{b'e} = 25$ pF i $C_{b'c} = 2$ pF. Zanemariti porast struje kolektora s naponom u_{CE} u NAP. Naponski ekvivalent temperature $U_T = 25$ mV.

a) Izračunati struju I_{CQ} i napon U_{CEQ} u statičkoj radnoj točki.

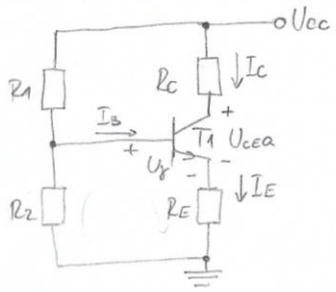
b) Nacrtati nadomjesnu shemu pojačala za dinamičku visokofrekvencijsku analizu.

c) Izračunati pojačanje $A_{Ig} = I_{iz}/I_g$ na srednjim frekvencijama.

d) Izračunati gornju graničnu frekvenciju pojačanja A_{Ig}.



a)



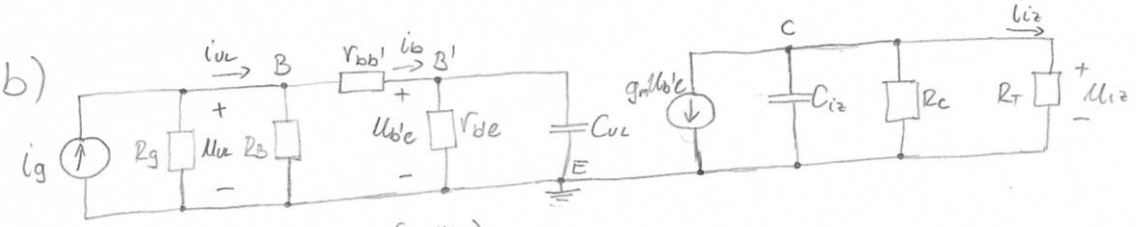
$$U_{BB} = \frac{R_1}{R_1 + R_2} U_{cc} \qquad R_B = R_1 \| R_2$$

$$I_{BQ} = \frac{U_{BB} - U_\gamma}{R_B + (1+\beta) R_E} \rightarrow I_{CQ} = \beta I_{BQ}$$

$$U_{CEQ} \approx U_{cc} - I_{CQ}(R_C + R_E)$$

$$r_{b'e} = \frac{U_T}{I_{BQ}}, \quad g_m = \frac{I_{CQ}}{U_T}$$

b)



$$K = \frac{U_{iz}}{U_{b'e}} = -g_m (R_C \| R_T)$$

$$C_{UL} = C_{b'e} + C_{b'c}(1-k)$$

$$C_{iz} = C_{b'c} \frac{K-1}{K}$$

c) $$A_{Igo} = \frac{i_{iz}}{i_g} = \boxed{\frac{i_{iz}}{u_{b'e}}} \cdot \boxed{\frac{u_{b'e}}{i_b}} \cdot \boxed{\frac{i_b}{i_g}}$$

$$i_{iz} = -g_m u_{b'e} \frac{R_C}{R_C + R_T} \rightarrow \frac{i_{iz}}{u_{b'e}} = -g_m \frac{R_C}{R_C + R_T}$$

$$u_{b'e} = r_{b'e} \cdot i_b \rightarrow \frac{u_{b'e}}{i_b} = r_{b'e}$$

$$i_b = \frac{R_g \| R_B}{(R_g \| R_B) + r_{bb'} + r_{b'e}} i_{ul}$$

$$A_{Igo} = -g_m \frac{R_C}{R_C + R_T} \cdot r_{b'e} \frac{R_g \| R_B}{(R_g \| R_B) + r_{bb'} + r_{b'e}}$$

d) $$\tau_{UL} = C_{UL} \cdot \left[(R_g \| R_B + r_{bb'}) \| r_{b'e} \right] \rightarrow \omega_{UL} = \frac{1}{\tau_{UL}}$$

$$\tau_{iz} = C_{iz} (R_C \| R_T) \rightarrow \omega_{iz} = \frac{1}{\tau_{iz}}$$

$$\omega_g = \min\{\omega_{UL}, \omega_{iz}\} \qquad f_g = \frac{\omega_g}{2\pi}$$

ZI 2013, 2017, 2019 *ZIR 2014* *LJIR 2018, 2019, 2020*

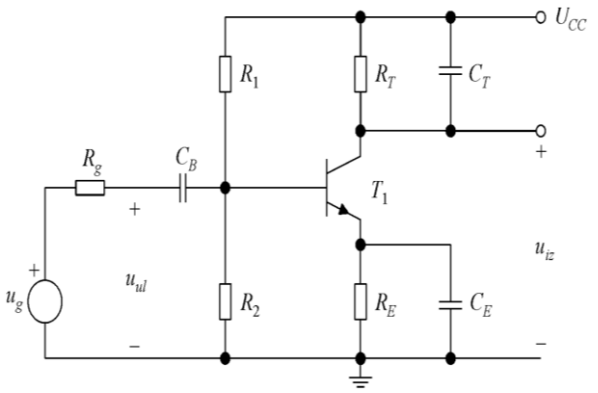
Za pojačalo sa slike zadano je:
$U_{CC} = 15$ V, $R_g = 1$ kΩ, $C_B = 2$ μF, $R_1 = 400$ kΩ, $R_2 = 100$ kΩ, $R_E = 500$ Ω, $R_T = 2$ kΩ, $C_T = 15$ pF i $C_E = 100$ μF.
Parametri oba tranzistora su $\beta \approx h_{fe} = 100$, $U_\gamma = 0{,}7$ V, $r_{bb'} = 50$ Ω, $C_{b'e} = 40$ pF i $C_{b'c} = 2$ pF. Zanemariti porast struje kolektora s naponom u_{CE} u NAP. Naponski ekvivalent temperature $U_T = 25$ mV.

a) Izračunati struju I_{CQ} i napon U_{CEQ} u statičkoj radnoj točki.

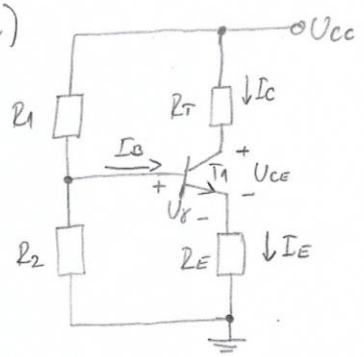
b) Nacrtati nadomjesnu shemu pojačala za dinamičku visokofrekvencijsku analizu.

c) Izračunati pojačanje $A_{Vg} = U_{iz}/U_g$ na srednjim frekvencijama.

d) Izračunati gornju graničnu frekvenciju pojačanja A_{Vg}.



a)



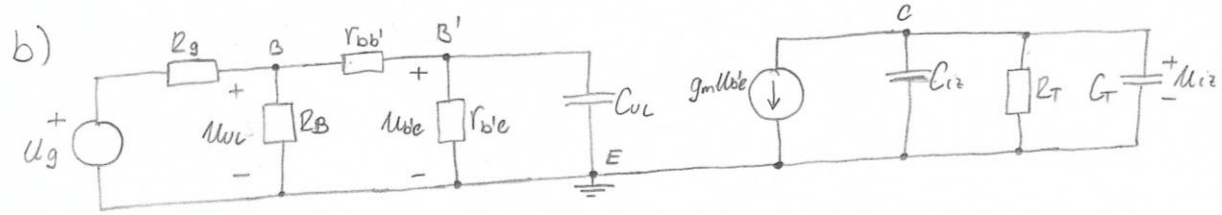
$$U_{BB} = \frac{R_2}{R_1+R_2} U_{CC} \qquad R_B = R_1 \| R_2$$

$$I_{BQ} = \frac{U_{BB} - U_\gamma}{R_B + (1+\beta)R_E} \rightarrow I_{CQ}$$

$$U_{CEQ} \approx U_{CC} - I_{CQ}(R_T + R_E)$$

$$r_{b'e} = \frac{U_T}{I_{BQ}}, \qquad g_m = \frac{I_{CQ}}{U_T}$$

b)



c)

$$A_{Vgo} = \frac{u_{iz}}{u_g} = \underbrace{\frac{u_{iz}}{u_{b'e}}}_{A_{V3}} \underbrace{\frac{u_{b'e}}{u_{ul}}}_{A_{V2}} \underbrace{\frac{u_{ul}}{u_g}}_{A_{V1}}$$

$$A_{V3} = \frac{u_{iz}}{u_{b'e}} = \frac{-g_m u_{b'e} R_T}{u_{b'e}} = -g_m R_T$$

$$A_{V2} = \frac{u_{b'e}}{u_{ul}} = \frac{r_{b'e}}{r_{bb'} + r_{b'e}}$$

$$A_{V1} = \frac{u_{ul}}{u_g} = \frac{R_B \| (r_{bb'} + r_{b'e})}{R_g + R_B \| (r_{bb'} + r_{b'e})}$$

$$A_{Vgo} = -g_m R_T \frac{r_{b'e}}{r_{bb'} + r_{b'e}} \frac{R_B \| (r_{bb'} + r_{b'e})}{R_g + R_B \| (r_{bb'} + r_{b'e})}$$

d)

$$K = \frac{u_{iz}}{u_{b'e}} = -g_m R_T$$

$$C_{uL} = C_{b'e} + C_{b'c}(1-K) \qquad C_{iz} = C_{b'c}\frac{K-1}{K}$$

$$\tau_{uL} = C_{uL}\left[(R_g \| R_B + r_{bb'}) \| r_{b'e}\right] \rightarrow \omega_{uL} = \frac{1}{\tau_{uL}}$$

$$\tau_{iz} = R_T(C_{iz} + C_T) \rightarrow \omega_{iz} = \frac{1}{\tau_{iz}}$$

$$\omega_g = \min\{\omega_{uL}, \omega_{iz}\} \rightarrow f_g = \frac{\omega_g}{2\pi}$$

LJIR 2020 *ZIR 2014*

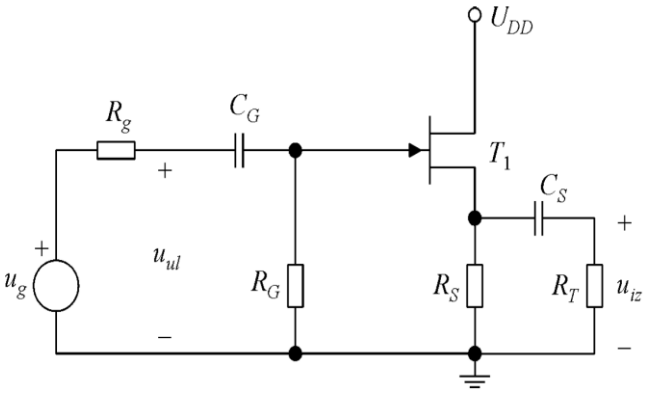
Za pojačalo sa slike zadano je:
$U_{DD} = 12$ V, $R_g = 1$ kΩ, $C_G = 40$ nF, $R_G = 1$ MΩ,
$R_S = 1$ kΩ, $C_S = 2$ μF i $R_T = 4$ kΩ.
Parametri FET-a su $I_{DSS} = 12$ mA, $U_P = -6$ V. Zanemariti porast struje odvoda s naponom u_{DS} u području zasićenja

a) Izračunati struju I_{DQ} i napone U_{GSQ} i U_{DSQ} u statičkoj radnoj točki.

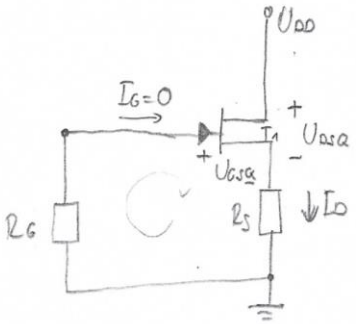
b) Nacrtati nadomjesnu shemu pojačala za dinamičku niskofrekvencijsku analizu

c) Izračunati pojačanje $A_V = U_{iz}/U_{ul}$ na srednjim frekvencijama

d) Izračunati donju graničnu frekvenciju pojačanja A_V.



a)

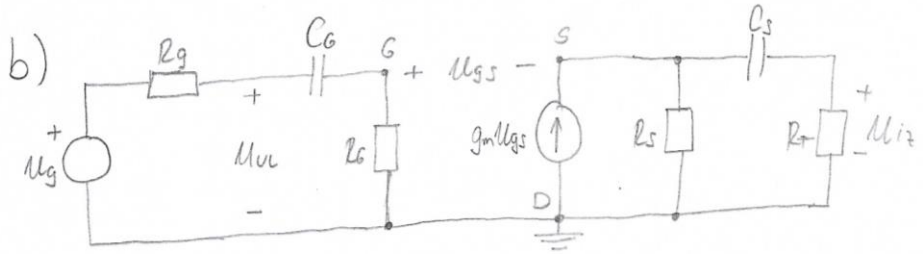


$$I_{DQ}R_S + U_{GSQ} = 0$$
$$I_{DQ} = I_{DSS}\left(1 - \frac{U_{GSQ}}{U_P}\right)^2 \Bigg\} \; U_{GSQ}^2 + \left(\frac{U_P^2}{R_S I_{DSS}} - 2U_P\right)U_{GSQ} + U_P^2 = 0$$

$$U_{DSQ} = U_{DD} - I_{DQ}R_S$$

$$g_m = \frac{\partial i_D}{\partial u_{GS}}\Big|_Q = -\frac{2I_{DSS}}{U_P}\left(1 - \frac{U_{GSQ}}{U_P}\right)$$

b)



c) $u_{iz} = g_m u_{gs}(R_S \| R_T)$
$u_{ul} = u_{gs} + u_{iz}$
$\Bigg\} A_{VO} = \frac{u_{iz}}{u_{ul}} = \frac{g_m(R_S \| R_T)}{1 + g_m(R_S \| R_T)}$

$$A_{VgO} = \frac{u_{iz}}{u_g} = \frac{g_m(R_S \| R_T)}{1 + g_m(R_S \| R_T)} \cdot \frac{R_G}{R_G + R_g}$$

d) $\tau_S = C_S\left(R_T + R_S \| \frac{1}{g_m}\right) \rightarrow \omega_S = \frac{1}{\tau_S}$

$\tau_G = C_G(R_G + R_g) \rightarrow \omega_G = \frac{1}{\tau_G}$

DIR 2018 zzv visokofrekv zad 2

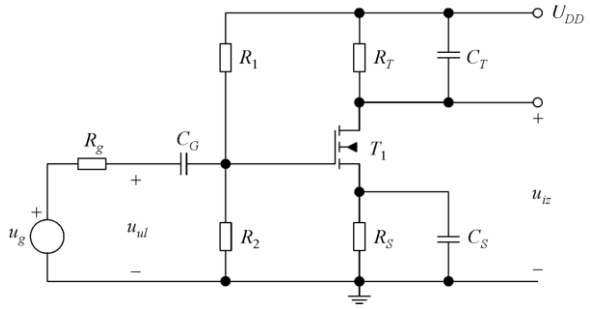
Za pojačalo sa slike zadano je:
$U_{DD} = 12$ V, $R_g = 5$ kΩ, $R_1 = 4$ MΩ, $R_2 = 2$ MΩ, $R_T = 1{,}5$ kΩ, $C_S = 15$ μF i $C_T = 4$ pF.
Parametri FET-a su $K = 1{,}5$ mA/V^2, $U_{GS0} = 1$ V, $C_{gs} = 2$ pF i $C_{gd} = 1$ pF. Zanemariti porast struje odvoda s naponom u_{DS} u području zasićenja.

a)) Odrediti otpor R_S s kojim će se postići struja $I_{DQ} = 3$ mA, te izračunati napon U_{DSQ}

b) Nacrtati nadomjesnu shemu pojačala za dinamičku visokofrekvencijsku analizu

c) te odrediti pojačanje $A_{Vg} = U_{iz}/U_g$ na srednjim frekvencijama

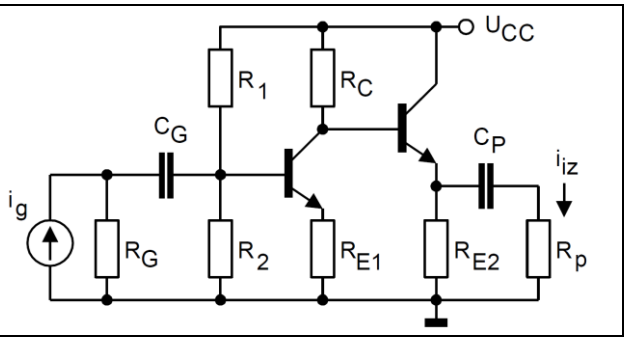
d) Izračunati gornju graničnu frekvenciju pojačanja A_{Vg}.



MI 2018 Primjer 4

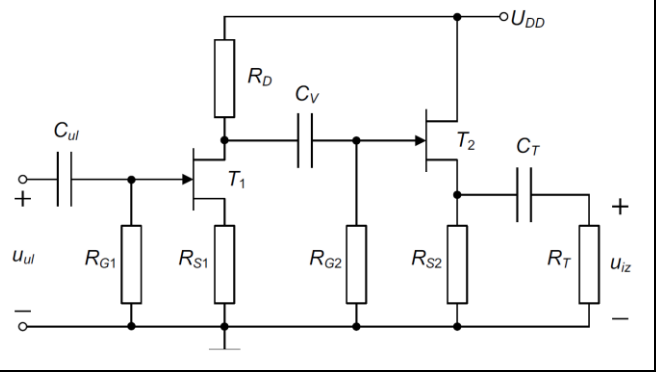
Izračunati strujno pojačanje $A_{Ig} = i_{iz}/i_g$ na srednjim frekvencijama te donju graničnu frekvenciju tog pojačanja.

Tranzistori imaju iste parametre: su $\beta \approx h_{fe} = 100$ i $h_{oe} = 0$.
Zadano je:
$R_g = 50$ kΩ, $R_1 = 40$ kΩ, $R_2 = 10$ kΩ, $R_C = 2$ kΩ
$R_{E1} = R_{E2} = 500$ Ω, $R_P = 100$ Ω, $C_G = 0{,}2$ μF i $C_P = 10$ μF



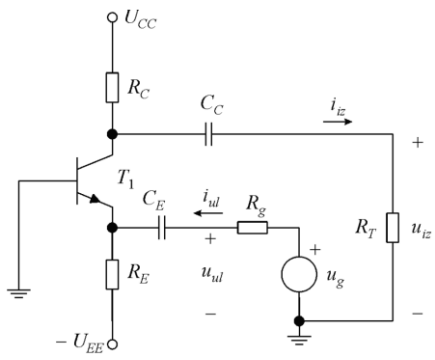
ZIR 2019 zzv niskofrekv zad3

Za pojačalo na slici izračunati naponsko pojačanje $A_{V0} = u_{iz}/u_{ul}$ na srednjim frekvencijama te donju graničnu frekvenciju tog pojačanja.
U statičkoj analiti zanemariti porast izlazne struje s izlaznim naponom u zasićenju. Zadano je: $R_{G1} = 1$ MΩ, $R_D = 6$ kΩ, $R_{S1} = 1$ kΩ, $R_{G2} = 1$ MΩ, $R_{S2} = 1$ kΩ, $R_T = 6$ kΩ, $C_{ul} = 10$ nF, $C_V = 10$ nF, $C_P = 0.2$ μF, $U_{DD} = 20$ V, $U_{P1} = U_{P2} = -4$ V, $I_{DSS1} = I_{DSS2} = 8$ mA, $\lambda_1 = \lambda_2 = 3.333 * 10^{-3}$ V^{-1}
$R_g = 50$ kΩ, $R_1 = 40$ kΩ, $R_2 = 10$ kΩ, $R_C = 2$ kΩ
$R_{E1} = R_{E2} = 500$ Ω, $R_P = 100$ Ω, $C_G = 0{,}2$ μF i $C_P = 10$ μF



ZIR 2019 zzv visokofrekv zad3

Za pojačalo sa slike odrediti naponsko pojačanje $A_{Vg} = U_{iz}/U_g$ na srednjim frekvencijama, te gornju graničnu frekvenciju tog pojačanja.
Zadano je:
$U_{CC} = U_{EE} = 12$ V, $R_g = 50$ Ω, $C_E = 150$ μF, $R_E = 4$ kΩ, $R_C = 2$ kΩ, $C_C = 2$ μF i $R_T = 3$ kΩ.
Parametri tranzistora su $\beta \approx h_{fe} = 100$, $U_\gamma = 0{,}7$ V, $C_{b'e} = 50$ pF i $C_{b'c} = 3$ pF. Zanemariti serijski otpor baze $r_{bb'}$ i porast struje kolektora s naponom u_{CE} u NAP. Naponski ekvivalent temperature $U_T = 25$ mV.



5. POJAČALA S POVRATNOM VEZOM

Za pojačalo na slici zadano je U_{CC}, R_{C1}, R_{B1} i R_{E2}. Parametri tranz su $\beta = h_{fe}$ i $U_\gamma = 0{,}7V$. Zanemariti serijski otpor baze $r_{bb'}$ i porast struje kolektora s naponom u_{CE} u NAP. Naponski ekvivalent temperature $U_T = 25mV$.

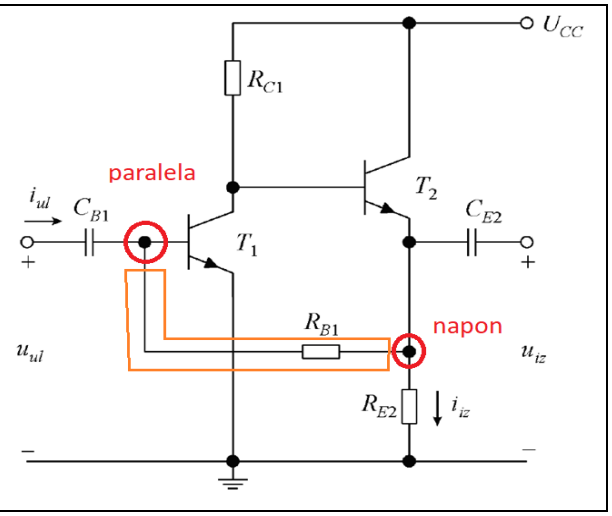
a) Izračunati statičku radnu točku.

b) Odrediti tip povratne veze i nacrtati *A*-granu pojačala bez povratne veze za mali signal.

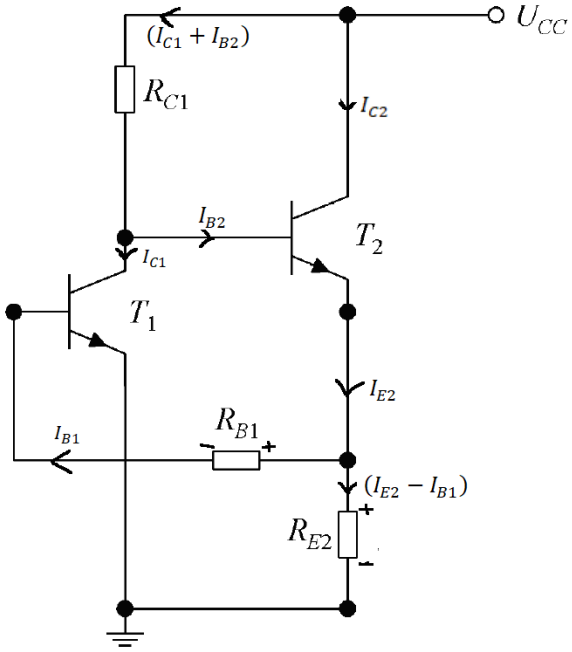
c) Odrediti pojačanje *A*-grane.

d) Odrediti koeficijent povratne veze β

e) Odrediti pojačanja $A_{Vf} = u_{iz}/u_{ul}$ i $A_{If} = i_{iz}/i_{ul}$.



a)



$$U_{CC} \approx \beta I_{BQ1} R_{C1} + U_{BEQ2} + I_{BQ1} R_{B1} + U_{BEQ1} \rightarrow I_{BQ1} \approx \frac{U_{CC} - 2U_{BEQ}}{\beta R_{C1} + R_{B1}}$$

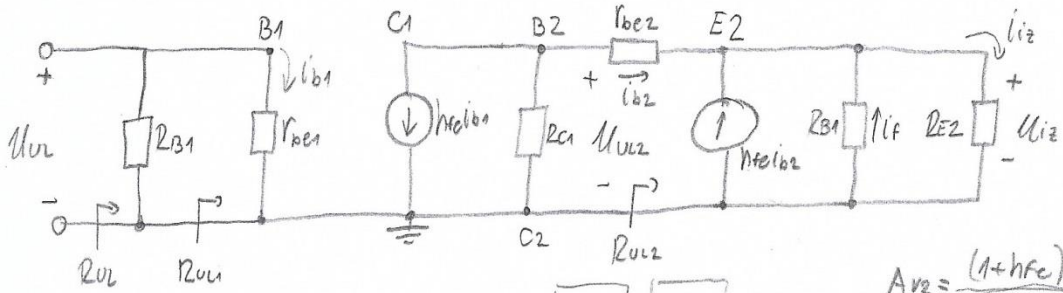
$$\left[(1+\beta) I_{BQ2} - I_{BQ1}\right] R_{E2} = I_{BQ1} R_{B1} + U_{BEQ1} \rightarrow I_{BQ2} = \frac{U_{BEQ} + I_{BQ1}(R_{B1} + R_{E2})}{(1+\beta) R_{E2}}$$

$$I_{CQ1} = \beta I_{BQ1}, \qquad I_{CQ2} = \beta I_{BQ2}$$

$$r_{be1} = \frac{U_T}{I_{BQ1}}, \qquad r_{be2} = \frac{U_T}{I_{BQ2}}$$

b) *Povratna veza - naponska-paralelna*

c,d,e)



$$R_M = \frac{u_{iz}}{i_{UL}} = \frac{\frac{u_{iz}}{u_{UL2}}}{\frac{1}{R_{UL}}} = R_{UL}\frac{u_{iz}}{u_{UL}} = R_{UL}\underbrace{\frac{u_{iz}}{u_{UL2}}}_{A_{V2}}\underbrace{\frac{u_{UL2}}{u_{UL}}}_{A_{V1}}$$

$$A_{V2} = \frac{(1+h_{fe})\,i_{b2}\,(R_{B1}\,//\,R_{E2})}{r_{be2}\cdot i_{b2} + (1+h_{fe})(R_{B1}\,//\,R_{E2})} = R_{UL2}$$

$$A_{V1} = \frac{-h_{fe}\,i_{b1}\,(R_{C1}\,//\,R_{UL2})}{r_{be1}\cdot i_{b1}}$$

R_{UL1}

$$R_{UL} = R_{B1}\,//\,r_{be1}$$

$$\beta = \frac{i_f}{i_{iz}} = \frac{i_f}{-i_f R_{B1}} = \frac{-1}{R_{B1}}$$

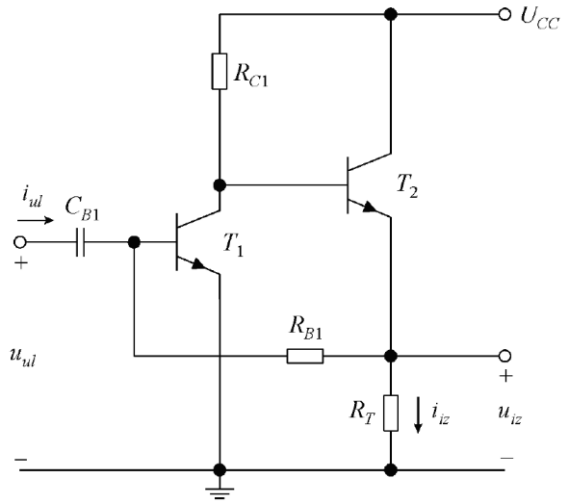
$$R_{Mf} = \frac{R_M}{1+\beta R_M}$$

$$A_{Vf} = \frac{u_{iz}}{u_{UL}} = \frac{u_{iz}}{i_{UL}\cdot R_{ULf}} = \frac{R_{Mf}}{R_{ULf}}$$

$$R_{ULf} = \frac{R_{UL}}{1+\beta R_M}$$

$$A_{If} = \frac{i_{iz}}{i_{UL}} = \frac{\frac{u_{iz}}{R_T}}{i_{UL}} = \frac{R_{Mf}}{R_T}$$

ZI 2016, 2018



shema malo drugačija, al je ustvari sve isto. Jedino se zamijeni R_{E2} s R_T

ZI 2013, 2017, 2019 JIR 2017 LJIR 2018, 2019, 2020 ZIR 2014

Za pojačalo na slici zadano je $U_{CC}, R_C, R_B, R_E, R_T$. Parametri tranz su $\beta_1 = h_{fe1}$, $\beta_2 = h_{fe2}$ i $U_\gamma = 0{,}7V$. Zanemariti serijski otpor baze r_{bb}, i porast struje kolektora s naponom u_{CE} u NAP. Naponski ekvivalent temperature $U_T = 25mV$.

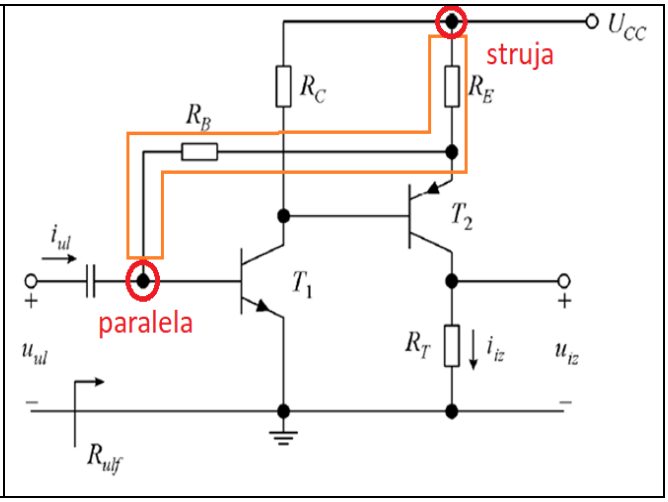
a) Izračunati statičku radnu točku.

b) Odrediti tip povratne veze i nacrtati *A*-granu pojačala bez povratne veze za mali signal uzevši u obzir opterećenje β-grane.

c) Odrediti pojačanje *A*-grane.

d) Odrediti koeficijent povratne veze β.

e) Odrediti pojačanja $A_{Vf} = u_{iz}/u_{ul}$ i $A_{If} = i_{iz}/i_{ul}$.



a)

$$U_{CC} \approx \beta_1 I_{BQ1} R_C + U_{BEQ2} + I_{BQ1} R_B + U_{BEQ1}, \quad U_{BEQ1} \approx -U_{BEQ2}$$

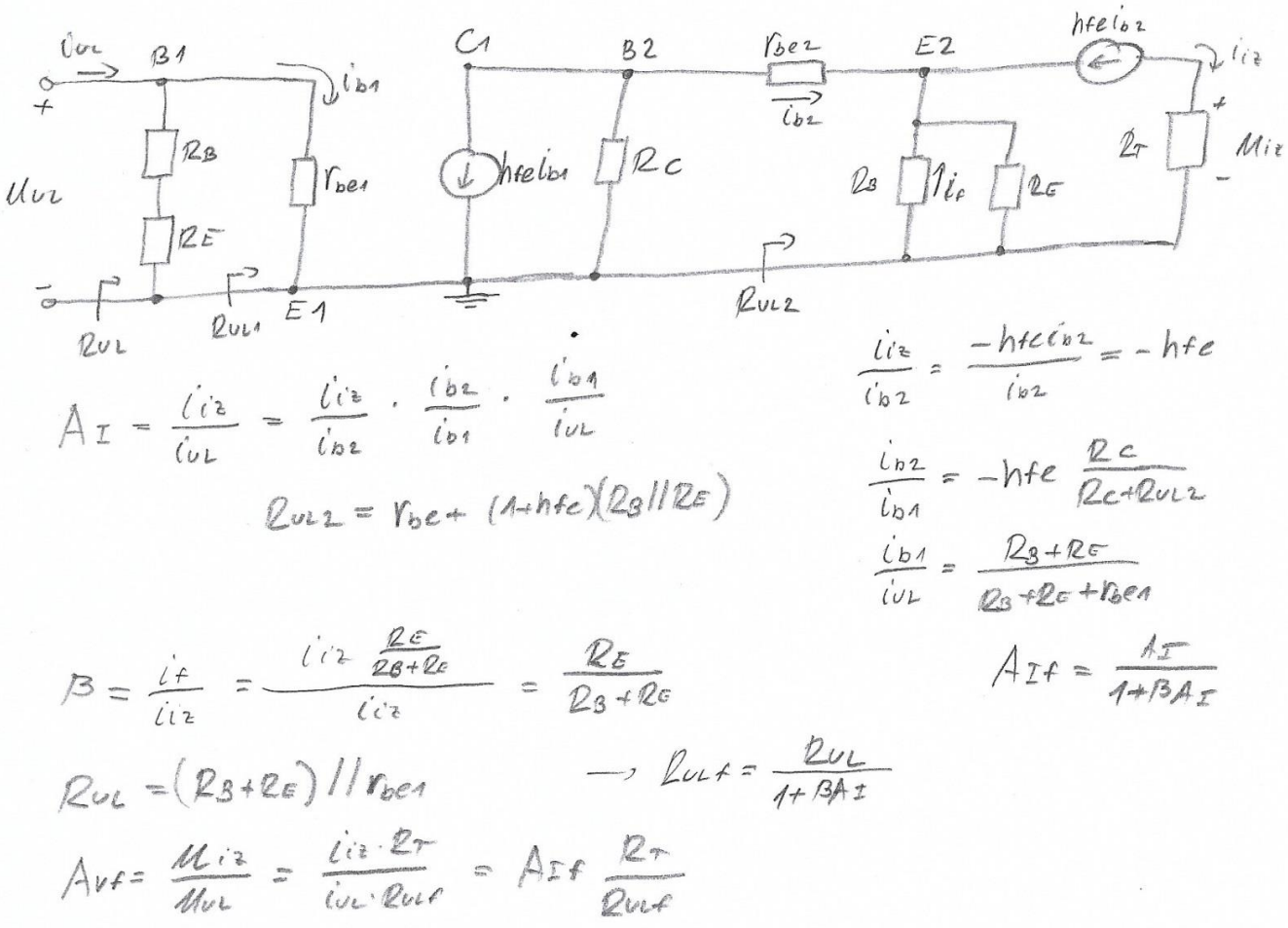
$$I_{BQ1} \approx \frac{U_{CC}}{\beta_1 R_C + R_B}$$

$$\beta_1 I_{BQ1} R_C \approx -\beta_2 I_{BQ2} R_E - U_{BEQ2} \rightarrow I_{BQ2} \approx \frac{\beta_1 I_{BQ1} R_C + U_{BEQ2}}{\beta_2 R_E}$$

$$I_{CQ1} = \beta_1 I_{BQ1}, \qquad I_{CQ2} = \beta_2 I_{BQ2}$$

$$r_{be1} = \frac{U_T}{I_{BQ1}}, \qquad r_{be2} = \frac{U_T}{I_{BQ2}}$$

b) *Povratna veza - strujna-paralelna*



LJIR 2014, 2017 ZIR 2017 zzv zad3(al je bez RT)

Za pojačalo na slici zadano je $U_{DD}, R_G, R_D, R_S, R_C, R_T$. Parametri tranz su $I_{DSS}, U_P, \beta \approx h_{fe}$ i $U_\gamma = 0{,}7V$. Zanemariti serijski otpor baze r_{bb}, te porast struje kolektora s naponom u_{CE} u NAP i struje odvoda s naponom u_{DS} u području zasićenja. Naponski ekvivalent temperature $U_T = 25mV$.

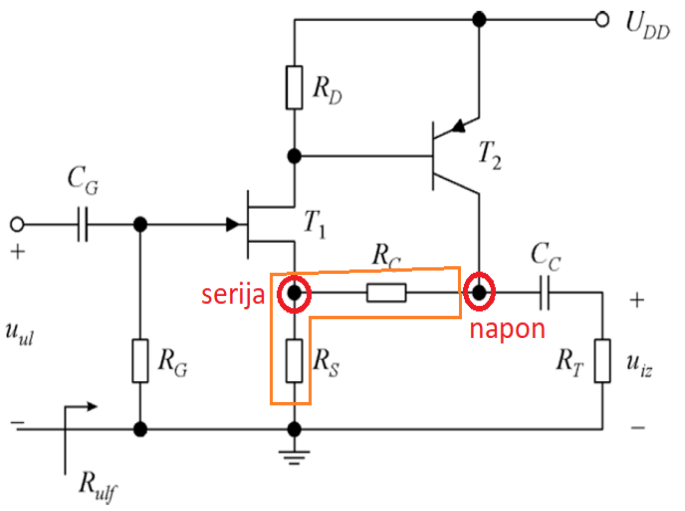
a) Izračunati statičku radnu točku.

b) Odrediti tip povratne veze i nacrtati *A*-granu pojačala bez povratne veze za mali signal.

c) Odrediti pojačanje *A*-grane.

d) Odrediti koeficijent povratne veze β.

e) Odrediti pojačanje $A_{Vf} = u_{iz}/u_{ul}$ i ulazni otpor R_{ulf} pojačala s povratnom vezom.



a)

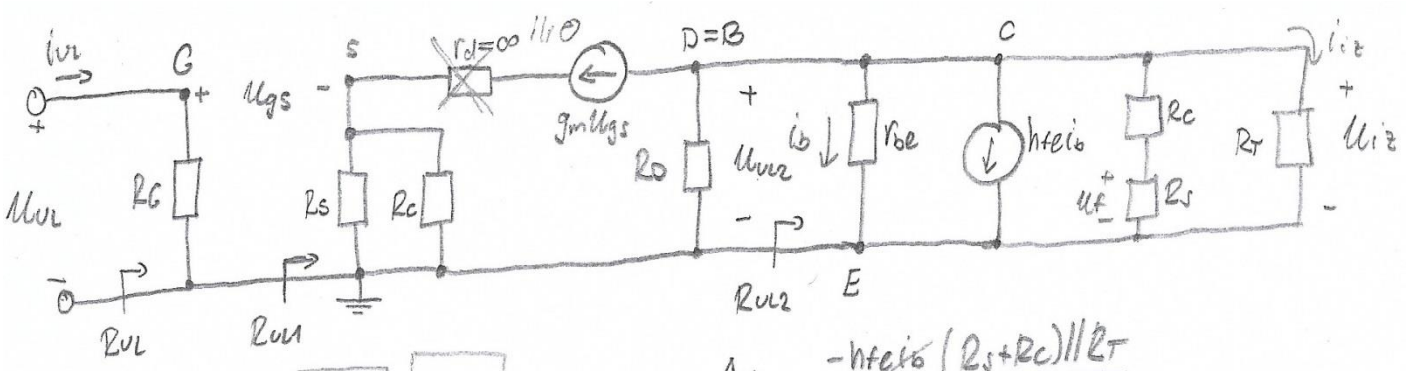
$$I_{DQ}R_D = -U_{BEQ} \;\rightarrow\; I_{DQ} = -\frac{U_{BEQ}}{R_D} = \frac{U_\gamma}{R_D}$$

$$I_{DQ} = I_{DSS}\left(1 - \frac{U_{GSQ}}{U_P}\right)^2 \;\rightarrow\; U_{GSQ} = U_P\left(1 - \sqrt{\frac{I_{DQ}}{I_{DSS}}}\right)$$

$$U_{GSQ} + (I_{DQ} - I_{CQ})R_S = 0 \;\rightarrow\; I_{CQ} = \frac{U_{GSQ}}{R_S} + I_{DQ}$$

$$g_m = -\frac{2I_{DSS}}{U_P}\left(1 - \frac{U_{GSQ}}{U_P}\right), \qquad r_{be} = \frac{U_T}{-I_{BQ2}} = \frac{\beta U_T}{-I_{CQ2}}$$

b) *Povratna veza - naponska-serijska*



$$A_V = \frac{u_{iz}}{u_{ul}} = \frac{u_{iz}}{u_{ul2}} \cdot \frac{u_{ul2}}{u_{ul}}$$

A_{V2} A_{V1}

$$A_{V2} = \frac{-h_{fe}(R_S + R_C)\|R_T}{i_b \cdot r_{be}}$$

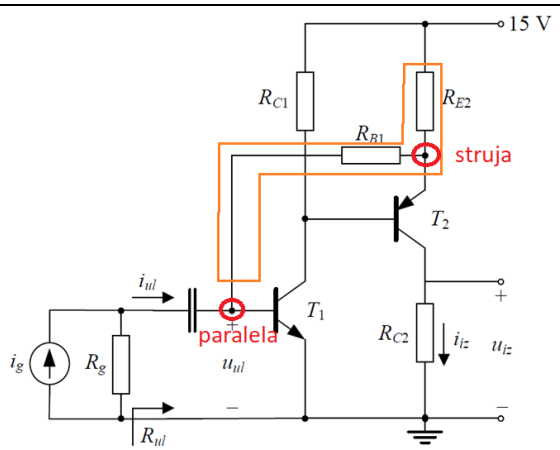
$$A_{V1} = \frac{-g_m u_{gs}(R_D \| r_{be})}{u_{gs} + g_m u_{gs}(R_S \| R_C)}$$

$$\beta = \frac{u_f}{u_{iz}} = \frac{R_S}{R_S + R_C}$$

$$A_{Vf} = \frac{A_V}{1 + \beta A_V}$$

$R_{ul1} = \infty \rightarrow R_{ulf} = R_{ul1}(1 + \beta A_V) = \infty \Rightarrow R_{ulf} = R_{ul1f} \| R_G = R_G$

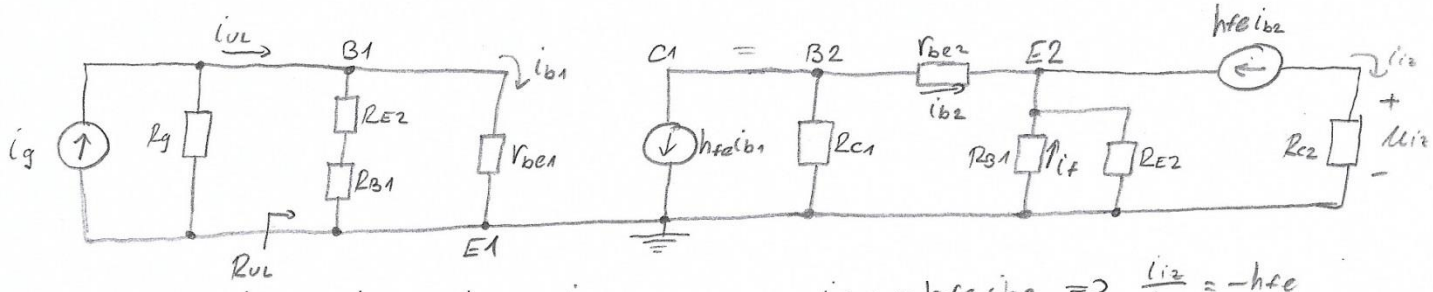
Za pojačalo s povratnom vezom izračunati: $A_{If} = \frac{i_{iz}}{i_{ul}}$, $A_{Vf} = \frac{u_{iz}}{u_{ul}}$, $A_{Igf} = \frac{i_{iz}}{i_g}$. Zadano je R_g, R_{B1}, R_{C1}, R_{C2}, R_{E2}, $\beta_1 \approx h_{fe1}$, $\beta_2 \approx h_{fe2}$ i $U_\gamma = 0{,}7V$. Za oba tranzistora zanemariti porast struje kolektora s naponom u_{CE} u NAP. Naponski ekvivalent temperature $U_T = 25mV$.



$$U_{CC} = R_{E2}(-I_{BQ2} - I_{CQ2} + I_{BQ1}) + I_{BQ1}R_{B1} + U_{BEQ1}$$
$$R_{C1}(I_{CQ1} - I_{BQ2}) + U_{BEQ2} + R_{E2}(I_{BQ2} + I_{CQ2} - I_{BQ1}) = 0$$

$$U_{BEQ1} = U_\gamma,\ U_{BEQ2} = -U_\gamma = -U_{BEQ1}$$
$$I_{BQ1} = \frac{U_{CC}}{\beta_1 R_{C1} + R_{B1}}$$
$$-I_{BQ2} = \frac{I_{BQ1}\beta_1 R_{C1} + U_{BEQ2}}{(1+\beta_2)R_{E2}}$$
$$r_{be1} = \frac{U_T}{I_{BQ1}},\quad r_{be2} = \frac{U_T}{-I_{BQ2}},\quad r_{ce} \to \infty$$

Povratna veza - strujna-paralelna



$$A_I = \frac{i_{iz}}{i_{UL}} = \frac{i_{iz}}{i_{b2}} \cdot \frac{i_{b2}}{i_{b1}} \cdot \frac{i_{b1}}{i_{UL}}$$

$$i_{iz} = -h_{fe} i_{b2} \Rightarrow \frac{i_{iz}}{i_{b2}} = -h_{fe}$$

$$i_{b2} = \frac{-h_{fe} i_{b1} \cdot R_{C1}}{R_{C1} + r_{be2} + (1+h_{fe})(R_{B1} \| R_{E2})}$$

$$i_{b1} = \frac{(R_{E2} + R_{B1})}{R_{E2} + R_{B1} + r_{be1}} i_{UL}$$

$$\beta = \frac{i_f}{i_{iz}} = \frac{R_{E2}}{R_{B1} + R_{E2}}$$

$$A_{If} = \frac{A_I}{1 + \beta A_I}$$

$$R_{UL} = (R_{E2} + R_{B1}) \| r_{be1}$$

$$R_{ULf} = \frac{R_{UL}}{1 + \beta A_I}$$

$$A_{Vf} = \frac{u_{iz}}{u_{UL}} = \frac{i_{iz} \cdot R_T}{i_{UL} \cdot R_{ULf}} = A_{If} \frac{R_T}{R_{ULf}}$$

$$A_{Igf} = \frac{i_{iz}}{i_g} = \frac{i_{iz}}{i_{UL}} \cdot \frac{i_{UL}}{i_g} = A_{If} \frac{R_g}{R_g + R_{ULf}}$$

6. STABILNOST P.V.

ZADATAK 5. (6 bodova) U pojačalu s povratnom vezom prijenosna funkcija osnovnog pojačala i koeficijent povratne veze su

$$A(j\omega)=\frac{-10^4\left(1+j\omega/10^6\right)}{\left(1+j\omega/10^4\right)\left(1+j\omega/10^5\right)}\,, \qquad \beta(j\omega)=\frac{\beta_0}{1+j\omega/10^4}$$

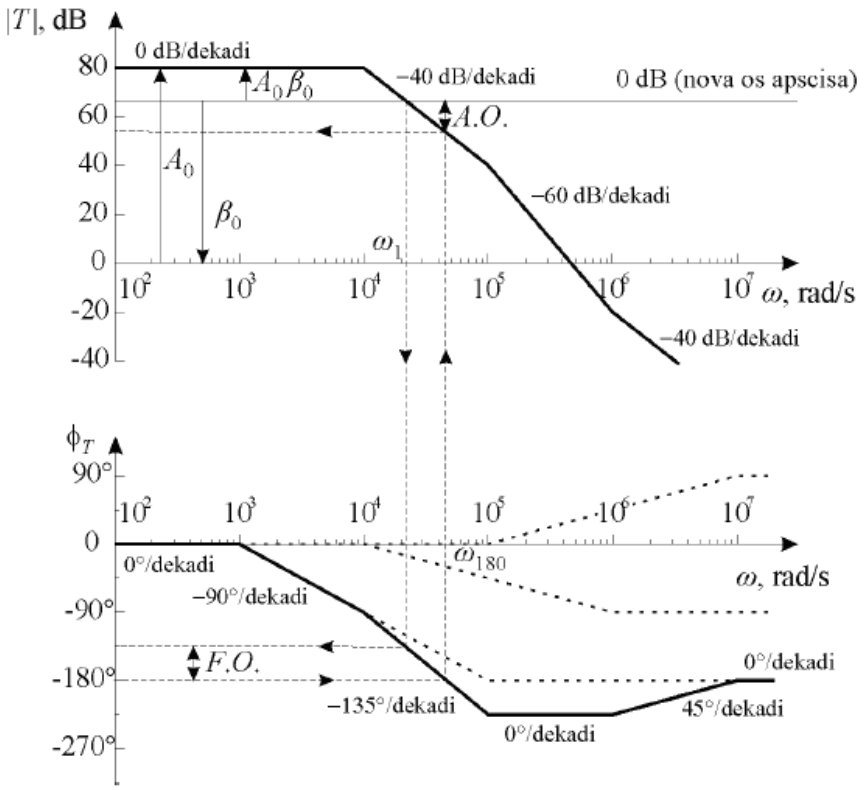
Grafičkim postupkom crtanjem aproksimativnog Bodeovog dijagrama odrediti β_0 uz koje će pojačalo biti stabilno s faznim osiguranjem $F.O.=45°$. Koliko je pri tome amplitudno osiguranje?

Na dijagramima označiti koordinatne osi, a u aproksimiranim karakteristikama upisati nagibe pojedinih odsječaka. (Bodeov dijagram – **4 boda**, određivanje β_0 – **1 bod**, A.O. – **1 bod**)

5. zadatak

$$A(j\omega)=\frac{-10^4\left(1+j\omega/10^6\right)}{\left(1+j\omega/10^4\right)\left(1+j\omega/10^5\right)}\,, \qquad \beta(j\omega)=\frac{\beta_0}{1+j\omega/10^4}\,.$$

$$\text{Uz } \beta_0=-1 \;\rightarrow\; T(j\omega)=\beta(j\omega)A(j\omega)=\frac{10^4\left(1+j\omega/10^6\right)}{\left(1+j\omega/10^4\right)^2\left(1+j\omega/10^5\right)}\,.$$



$$\phi_T(j\omega_{180})=-180° \;\rightarrow\; \left|T(j\omega_{180})\right|=\left|\beta(j\omega_{180})A(j\omega_{180})\right|=A.O.=-13\text{ dB},$$

$$20\log\left|\beta_0\right|=20\log\left|\beta_0 A_0\right|-20\log\left|A_0\right|=-67\text{ dB} \;\rightarrow\; \beta_0=-0,45\cdot10^{-3},$$

$$\left|T(j\omega_1)\right|=0\text{ dB} \;\rightarrow\; \phi_T(j\omega_1)=-135° \;\rightarrow\; F.O.=\phi_T(j\omega_1)+180°=45°.$$

ZI 2019, LJIR 2018. LJIR 2019

Zadatak 3 – 7 bodova

U pojačalu s povratnom vezom prijenosna funkcija osnovnog pojačala i koeficijent povratne veze su

$$A(j\omega)=\frac{-10^4\left(1+j\omega/10^5\right)}{\left(1+j\omega/10^4\right)\left(1+j\omega/10^6\right)^2}\,, \qquad \beta(j\omega)=\frac{\beta_0}{1+j\omega/10^6}\,,$$

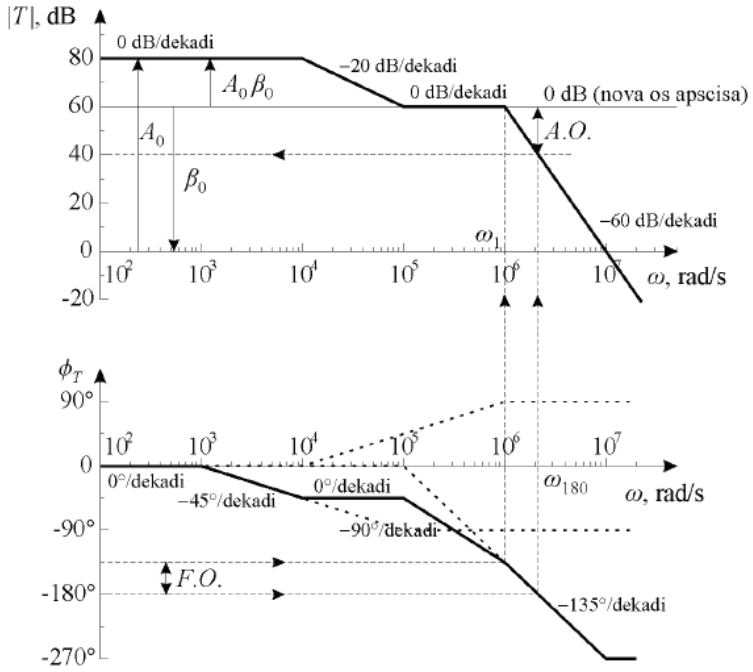
Grafičkim postupkom crtanjem Bodeovog dijagrama odrediti β_0 uz koje će pojačalo biti stabilno s faznim osiguranjem $F.O.=45°$. Koliko je pri tome amplitudno osiguranje?
Na dijagramima označiti koordinatne osi, a u aproksimiranim karakteristikama upisati nagibe pojedinih odsječaka.
(Bodeov dijagram – 4 boda, određivanje β_0 – 2 boda, $A.O.$ – 1 bod)

ZI 2013

3. zadatak

$$A(j\omega)=\frac{-10^4\left(1+j\omega/10^5\right)}{\left(1+j\omega/10^4\right)\left(1+j\omega/10^6\right)^2}\,, \qquad \beta(j\omega)=\frac{\beta_0}{1+j\omega/10^6}\,.$$

$$\text{Uz } \beta_0=-1 \;\rightarrow\; T(j\omega)=\beta(j\omega)A(j\omega)=\frac{10^4\left(1+j\omega/10^5\right)}{\left(1+j\omega/10^4\right)\left(1+j\omega/10^6\right)^3}\,.$$



$$\phi_T(j\omega_1)=F.O.-180°=-135° \;\rightarrow\; \left|T(j\omega_1)\right|=\left|\beta(j\omega_1)A(j\omega_1)\right|=1=0\ \text{dB}\,,$$

$$\beta_0=-0{,}001\,,$$

$$\phi_T(j\omega_{180})=-180° \;\rightarrow\; \left|T(j\omega_{180})\right|=-20\ \text{dB}=A.O.$$

Zadatak 3 – 7 bodova

U pojačalu s povratnom vezom prijenosna funkcija osnovnog pojačala i koeficijent povratne veze su

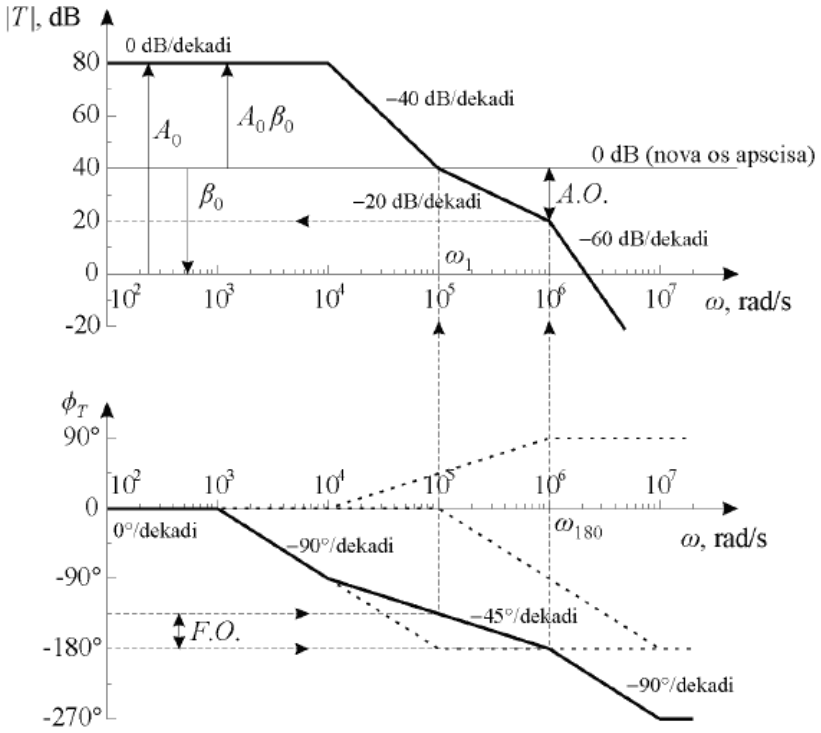
$$A(j\omega)=\frac{10^4}{\left(1+j\omega/10^4\right)^2\left(1+j\omega/10^6\right)}\,, \qquad \beta(j\omega)=\beta_0\frac{1+j\omega/10^5}{1+j\omega/10^6}\,.$$

Grafičkim postupkom crtanjem Bodeovog dijagrama odrediti β_0 uz koje će pojačalo biti stabilno s faznim osiguranjem $F.O.=45°$. Koliko je pri tome amplitudno osiguranje $A.O.$?
Na dijagramima označiti koordinatne osi, a u aproksimiranim karakteristikama upisati nagibe pojedinih odsječaka.
(Bodeov dijagram – 4 boda, određivanje β_0 – 2 boda, $A.O.$ – 1 bod)

3. zadatak

$$A(j\omega)=\frac{10^4}{\left(1+j\omega/10^4\right)^2\left(1+j\omega/10^6\right)}\,, \qquad \beta(j\omega)=\beta_0\frac{1+j\omega/10^5}{1+j\omega/10^6}$$

$$\text{Uz } \beta_0=1 \;\rightarrow\; T(j\omega)=\beta(j\omega)A(j\omega)=\frac{10^4\left(1+j\omega/10^5\right)}{\left(1+j\omega/10^4\right)^2\left(1+j\omega/10^6\right)^2}$$



$$\phi_T(j\omega_1)=F.O.-180°=45°-180°=-135° \;\rightarrow\; \left|T(j\omega_1)\right|=\left|\beta(j\omega_1)A(j\omega_1)\right|=1=0\ \text{dB}\,,$$

$$20\log\left|\beta_0\right|=20\log\left|\beta_0 A_0\right|-20\log\left|A_0\right|=40-80=-40\ \text{dB}\,,$$

$$\beta_0=0{,}01\,,$$

$$\phi_T(j\omega_{180})=-180° \;\rightarrow\; A.O.=-\left|T(j\omega_{180})\right|=20\ \text{dB}$$

ZI 2017

Zadatak 4 – 6 bodova

U pojačalu s povratnom vezom zadani su prijenosna funkcija osnovnog pojačala i koeficijent povratne veze:

$$A(j\omega)=\frac{-10^3\left(1+j\omega/10^5\right)}{\left(1+j\omega/10^4\right)\left(1+j\omega/10^6\right)^2}\,, \qquad \beta(j\omega)=\frac{\beta_0}{1+j\omega/10^6}\,.$$

Grafičkim postupkom (crtanjem Bodeovog dijagrama) odrediti β_0 uz koje će pojačalo biti stabilno s faznim osiguranjem $F.O.=45°$. Koliko je pri tome amplitudno osiguranje?
Na dijagramima označiti koordinatne osi, a u aproksimiranim karakteristikama upisati nagibe pojedinih odsječaka.
(Bodeov dijagram: **4 boda**, β_0: **1 bod**, $A.O.$: **1 bod**)

ZI 2012

Zadatak 3 – 7 bodova

U pojačalu s povratnom vezom prijenosna funkcija osnovnog pojačala je

$$A(j\omega)=\frac{-10^{20}}{\left(10^5+j\omega\right)\left(10^6+j\omega\right)^2}\,,$$

a koeficijent povratne veze β neovisan je o frekvenciji. Grafičkim postupkom crtanjem Bodeovog dijagrama odrediti β uz koje će pojačalo biti stabilno s amplitudnim osiguranjem $A.O.=-10$ dB. Koliko je pri tome fazno osiguranje?
Na dijagramima označiti koordinatne osi, a u aproksimiranim karakteristikama upisati nagibe pojedinih odsječaka.
(Bodeov dijagram – 4 boda, određivanje β – 2 boda, $F.O.$ – 1 bod)

ZIR 2019

Zadatak 5. - 8 bodova

Prijenosne funkcije A i β – grane su

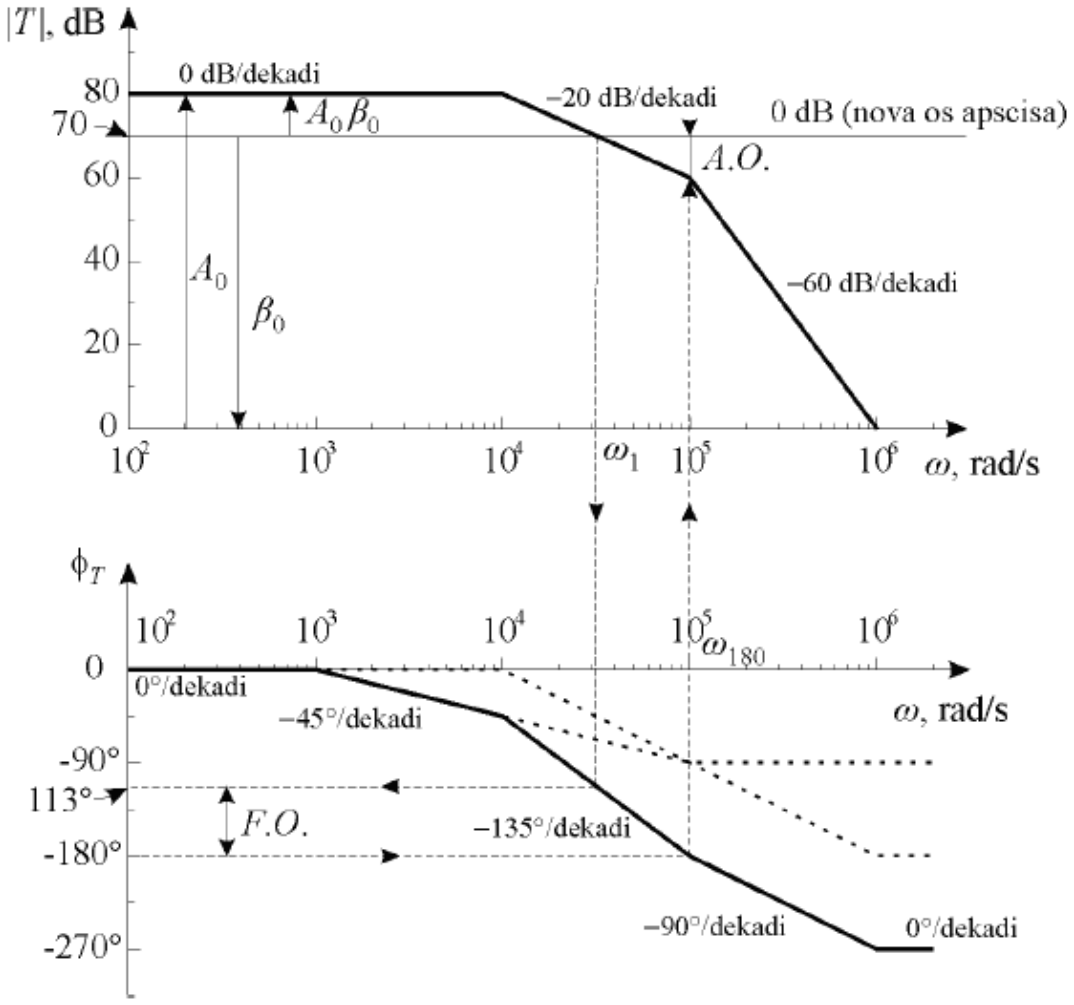
$$A(jf)=-\frac{10^3}{\left(1+jf/10^4\right)\left(1+jf/10^5\right)^2}\,, \quad \beta(jf)=\beta_0\frac{1+jf/10^5}{1+jf/10^6}\,.$$

Odrediti β_0 tako da fazno osiguranje bude 45°. Koliko je amplitudno osiguranje za taj slučaj?

5. zadatak

$$A(j\omega)=\frac{-10^{18}}{\left(10^4+j\omega\right)\left(10^5+j\omega\right)^2}\ .$$

$$\text{Uz } \beta_0=-1 \quad\rightarrow\quad T(j\omega)=\beta_0 A(j\omega)=\frac{10^4}{\left(1+j\omega/10^4\right)\left(1+j\omega/10^5\right)^2}\ .$$



$$\phi_T(j\omega_{180})=-180^\circ \quad\rightarrow\quad \left|T(j\omega_{180})\right|=A.O.=-10\ \text{dB},$$

$$20\log\left|\beta_0\right|=20\log\left|\beta_0 A_0\right|-20\log\left|A_0\right|=-70\ \text{dB}, \quad \beta_0=-3{,}16\cdot10^{-4},$$

$$\left|T(j\omega_1)\right|=1=0\ \text{dB} \quad\rightarrow\quad \phi_T(j\omega_1)=-112{,}5^\circ,$$

$$F.O.=\phi_T(j\omega_1)+180^\circ=67{,}5^\circ$$