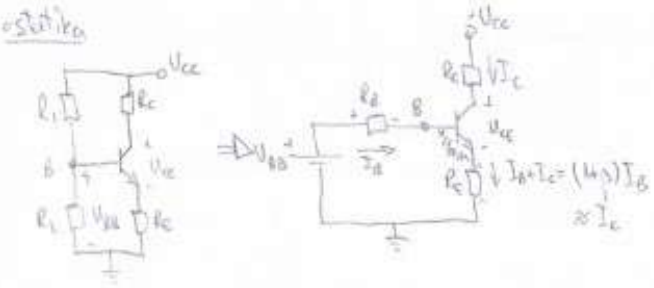
Prostor za rješavanje:

① $R_1 = 8.2\,k\Omega$, $R_2 = 3.3\,k\Omega$, $R_C = 1.8\,k\Omega$, $R_E = 970\,\Omega$, $R_T = 1\,k\Omega$, $U_{CC} = 12\,V$, $U_{BEA} = U_\gamma = 0.7\,V$, $\beta = h_{fe} = 100$

shema



$$U_{BB} = \frac{R_2}{R_1+R_2}\cdot U_{CC} = 3.443\,V$$

$$R_B = R_1 \| R_2 = 2.353\,k\Omega$$

ulazni krug: $-U_{BB} + I_{BA}R_B + U_{BEA} + R_E(1+\beta)I_{BA} = 0$

$$I_{BA} = \frac{U_{BB} - U_{BEA}}{R_B + R_E(1+\beta)} = 2.734\cdot 10^{-5}\,A$$

$$I_{CA} = \beta I_{BA} = 2.734\,mA$$

izlazni krug: $U_{CC} = R_C \cdot I_{CA} + U_{CEA} + R_E(1+\beta)I_{BA}$ ($\approx I_{CA}$)

SRP... (x) $U_{CEA} = U_{CC} - (R_C+R_E)I_{CA} = 4.417\,V$

$I_{CA} = 0$: $U_{CEA} = U_{CC} = 12\,V$

$U_{CE} = 0$: $I_{CA} = \frac{U_{CC}}{R_C+R_E} = 4.33\,mA$ } SRT

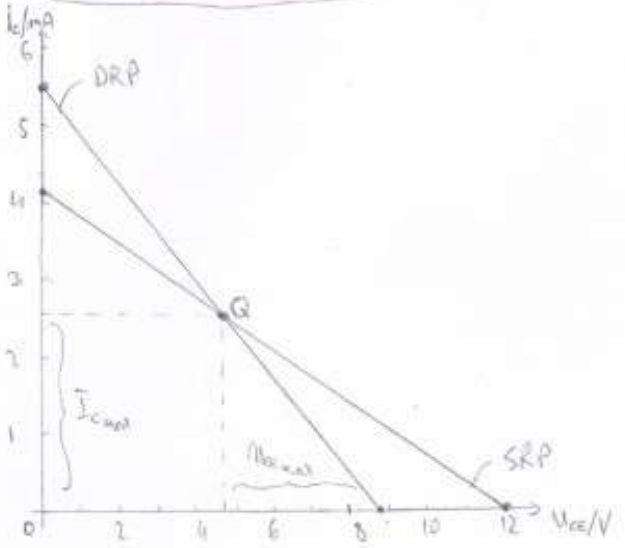
$$\Delta U_{CE} = U_{CC} - U_{CEA} = 4.41\,V \qquad \Delta i_c = i_c - I_{CA} = 2.745\,mA$$

$$U_{CE\,max} = \min(\Delta U_{CE}, U_{CEA}) = \Delta U_{CE} = 4.41\,V$$

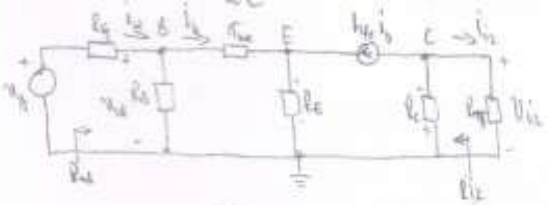
$U_{CE\,max} = U_{ic\,max} = 4.41\,V$

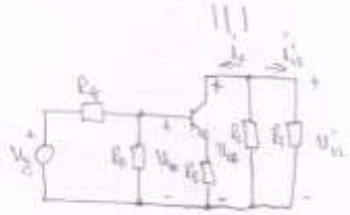
$$i_{c\,max} = \min(\Delta i_c, I_{CA}) = 2.734\,mA$$

$$i_{izmax} = i_{c\,max}\cdot\frac{R_C}{R_C+R_i} = 1.758\,mA$$



a) $C_E = \emptyset$, $X_C = \frac{1}{\omega C} = \infty$ → EMITERSKA DEGEN.





$$U_{CE} = -i_c(R_T \| R_C) - i_c \cdot R_E = -i_c(R_T \| R_C + R_E)$$

(x) $(U_{CE} - U_{CEA}) = -(i_c - I_{CA})(R_T \| R_C + R_E)$ .... DRP

ΔU_{CE} Δi_c

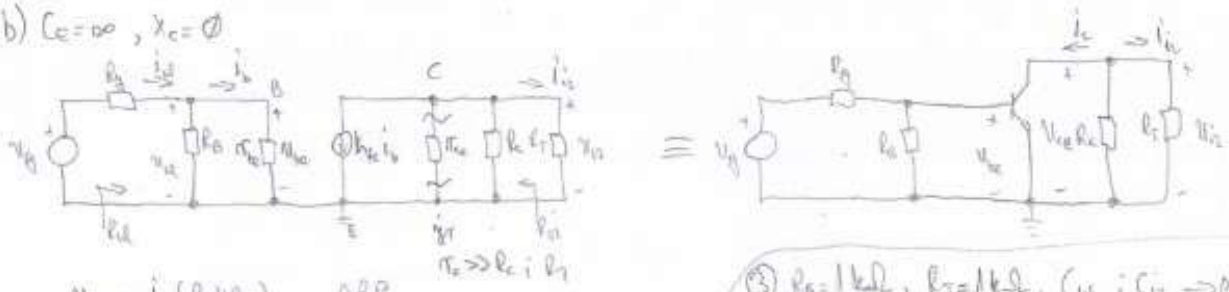
$i_c = 0$: $U_{CE} = U_{CEA} + I_{CA}(R_E + R_T \| R_C) = 8.837\,V$

$U_{CE} = 0$: $-U_{CEA} = -i_c(R_E + R_T \| R_C) + I_{CA}(R_E + R_T \| R_C)$

$$i_c = I_{CA} + \frac{U_{CEA}}{R_E + R_T \| R_C} = 5.479\,mA$$ } DRT

Prostor za rješavanje:

b) $C_E = \infty$, $X_C = \emptyset$



$r_e \gg R_C$ i R_T

$U_{CE} = -i_c (R_C \| R_T)$ ... DRP

$(U_{CE} - U_{CEQ}) = -(i_c - I_{CQ})(R_C \| R_T)$

ΔU_{CE} Δi_c

$U_{CE}=0$: $-U_{CEQ} = -I_{CQ}(R_C \| R_T) + I_{CQ}(R_C \| R_T)$

$i_c = I_{CQ} + \frac{U_{CEQ}}{R_C \| R_T} = 9.62\,mA$ //

$i_c = \emptyset$: $U_{CE} = U_{CEQ} + I_{CQ}(R_C \| R_T) = 6.185\,V$ // } DRT

$\Delta U_{CE} = U_{CE} - U_{CEQ} = 1.758\,V$ //

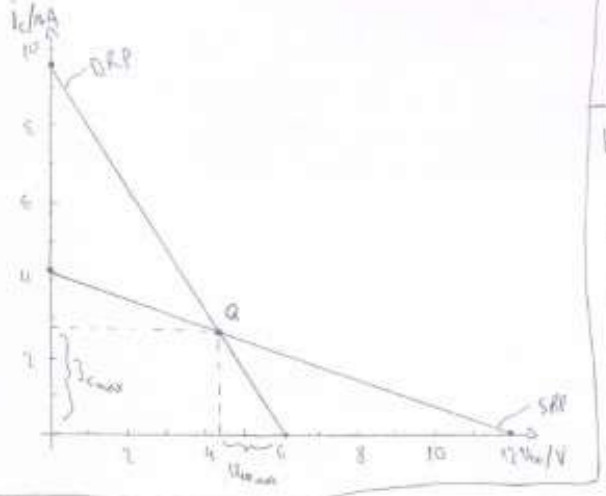
$\Delta i_c = i_c - I_{CQ} = 6.886\,V$ //

$U_{CE\,max} = \min(\Delta U_{CE}, U_{CEQ}) = 1.758\,V$ //

$U_{CE\,max} = U_{ir\,max} = 1.758\,V$

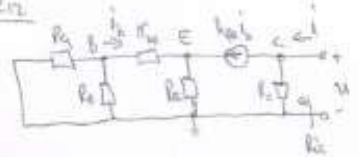
$i_{c\,max} = \min(\Delta i_c, I_{CQ}) = 2.734\,mA$ //

$i_{ir\,max} = i_{c\,max} \frac{R_C}{R_C + R_T} = 1.758\,mA$



$A_{Vg} = \frac{U_{ir}}{U_{ul}} \cdot \frac{U_{ul}}{U_g} = A_V \cdot \frac{R_{ul}}{R_g + R_{ul}} = -0.453$ //

R_{iz}



$i = \frac{u}{R_C} + h_{fe} i_b$

$u_E = (1 + h_{fe}) i_b R_E = -i_b (R_G \| R_B + r_{be})$

$i_b = \emptyset$

$R_{iz} = \frac{u}{i} = R_C$

$R_{iz} = R_C = 1.82\,k\Omega$

③ $R_G = 1\,k\Omega$, $R_T = 1\,k\Omega$, ω ; $C_{iz} \to \infty$

a) $C_E = \infty$, $X_C = \emptyset$ → ista shema kao (2b)

$R_B = R_1 \| R_2 = 2353\,\Omega$ // $r_{be} = \frac{U_T}{I_{BQ}} = 946\,\Omega$ //

$R_{ul} = \frac{U_{ul}}{i_{ul}} = \frac{i_{ul} \cdot (R_B \| r_{be})}{i_{ul}} = R_B \| r_{be} = 675\,\Omega$ //

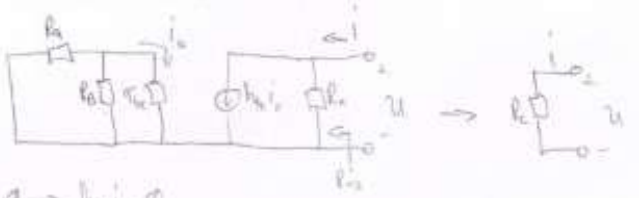
$A_V = \frac{U_{iz}}{U_{ul}} = \frac{-h_{fe} i_b (r_{ce} \| R_C \| R_T)}{i_b r_{be}} = -\frac{h_{fe}}{r_{be}} (R_C \| R_T) = -g_m (R_C \| R_T) = -67.96$ //

g_m

$A_I = \frac{i_{iz}}{i_{ul}} = \frac{\frac{U_{iz}}{R_T}}{\frac{U_{ul}}{R_{ul}}} = \frac{U_{iz}}{U_{ul}} \cdot \frac{R_{ul}}{R_T} = A_V \cdot \frac{R_{ul}}{R_T} = -45.87$ //

$A_{Vg} = \frac{U_{iz}}{U_{ul}} \cdot \frac{U_{ul}}{U_g} = A_V \cdot \frac{R_{ul}}{R_g + R_{ul}} = -27.33$ //

R_{iz}



$i_b = \emptyset \Rightarrow h_{fe} i_b = \emptyset$

$R_{iz} = \frac{U}{i} = \frac{i \cdot R_C}{i} = R_C \Rightarrow R_{iz} = R_C = 1.86\,\Omega$ //

b) $C_E = \emptyset$ → $X_C = \infty$ → EMITERSKA DEGEN., ista shema kao (2a)

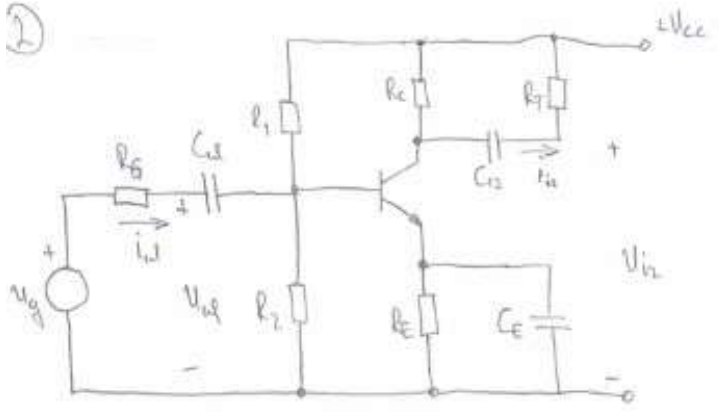
$R_{ul} = R_B \| \frac{i_b r_{be} + (i_b + h_{fe} i_b) R_E}{i_b} = R_B \| [r_{be} + (1 + h_{fe}) R_E] = 2.298\,k\Omega$ //

$A_V = \frac{U_{iz}}{U_{ul}} = \frac{i_{iz} \cdot R_T}{i_b (r_{be} + (1 + h_{fe}) R_E)} = -\frac{h_{fe} \cdot i_b \cdot \frac{R_C R_T}{R_C + R_T}}{i_b (r_{be} + (1 + h_{fe}) R_E)} = -h_{fe} \frac{R_C \| R_T}{r_{be} + (1 + h_{fe}) R_E} = -0.65$ //

$A_I = \frac{i_{iz}}{i_{ul}}$ $\quad i_{iz} = -h_{fe} i_b \frac{R_C}{R_C + R_T}$ $\quad i_b = i_{ul} \cdot \frac{R_B}{R_B + r_{be} + (1 + h_{fe}) R_E}$

$A_I = \frac{-h_{fe} \cdot i_b \cdot \frac{R_C}{R_C + R_T}}{\frac{i_b (R_B + r_{be} + (1 + h_{fe}) R_E)}{R_B}} = -h_{fe} \cdot \frac{R_C}{R_C + R_T} \cdot \frac{R_B}{R_B + r_{be} + (1 + h_{fe}) R_E} = -1.49$ //

1)



$R_1 = 8.2\,k\Omega$ $\quad \beta = h_{fe} = 100$

$R_2 = 3.3\,k\Omega$

$R_c = 1.8\,k\Omega$

$R_E = 970\,\Omega$

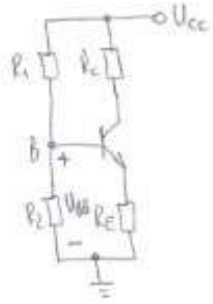
$R_T = 1\,k\Omega$

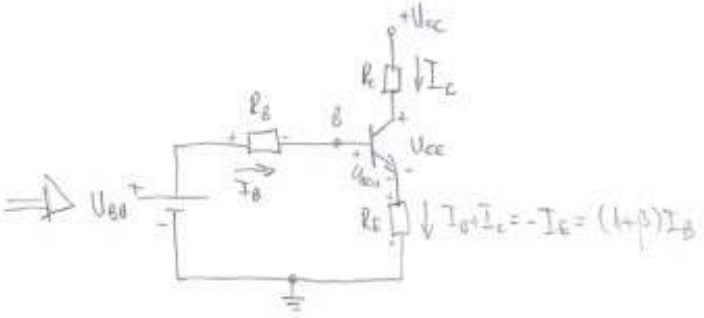
$C_E = \emptyset$

$U_{cc} = 12\,V$

$U_{BEQ} = U_\gamma = 0.7\,V$

STATIKA (kond. - prekid)





$$U_{BB} = \frac{R_2}{R_1+R_2}\cdot U_{cc} = \frac{3.3}{8.2+3.3}\cdot 12 = 3.443\,V \qquad R_B = R_1 \| R_2 = \frac{R_1 R_2}{R_1+R_2} = 2.353\,k\Omega$$

ulazni krug: $-U_{BB} + I_{BQ}R_B + U_{BEQ} + R_E(1+\beta)I_{BQ} = \emptyset$

$$I_{BQ}\left(R_B + (1+\beta)R_E\right) = U_{BB} - U_{BEQ}$$

$$I_{BQ} = \frac{U_{BB}-U_{BEQ}}{R_B+(1+\beta)R_E} = \frac{3.443-0.7}{2.353\cdot 10^3 + (1+100)\cdot 970} = 27.342\,\mu A$$

$$I_{CQ} = \beta\cdot I_{BQ} = 2.734\,mA$$

izlazni krug: $U_{cc} = R_c\cdot I_{CQ} + U_{CEQ} + R_E\underbrace{(1+\beta)I_{BQ}}_{\approx I_{CQ}}$

$$U_{CEQ} = U_{cc} - R_c I_{CQ} - R_E I_{CQ}$$

(*) $U_{CEQ} = U_{cc} - (R_c+R_E)I_{CQ} = 12 - (1.8\cdot 10^3 + 970)\cdot 2.734\cdot 10^{-3}$

$$U_{CEQ} = 4.427\,V$$

~~SRT (U_{CEQ}, I_{CQ})~~

dinamički parametri: $r_{be} = \frac{U_T}{I_{BQ}} = \frac{\frac{300}{11600}}{27.342\cdot 10^{-6}} = 946\,\Omega$

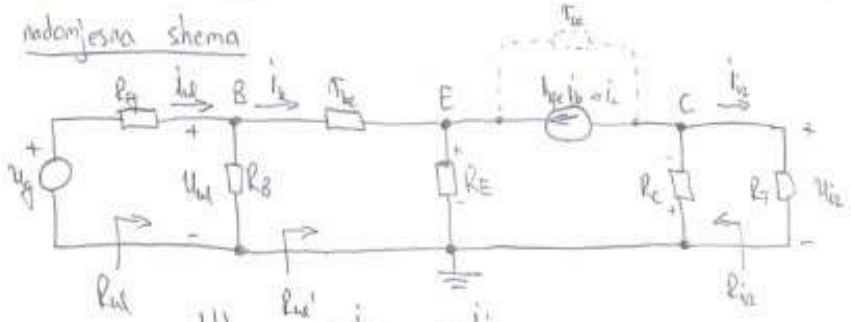
$$g_m = \frac{h_{fe}}{r_{be}} = \frac{\beta}{r_{be}} = \frac{100}{946} = 0.106$$

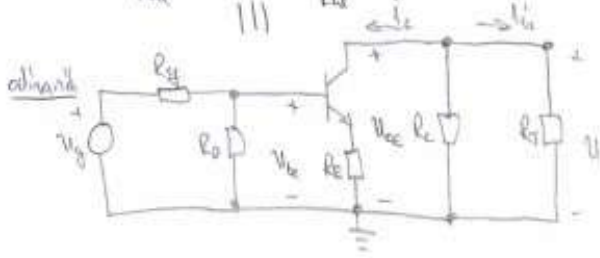
(*) $I_C = 0$: $U_{CEQ} = U_{cc} = 12\,V$

$U_C = \varphi$: $I_{CQ} = \frac{U_{cc}}{R_c+R_E} = \frac{12}{1800+970} = 4.33\,mA$ } SRT

a) $C_E = \emptyset$ $\quad X_c = \frac{1}{\omega C} = \infty \rightarrow$ EMITERSKA DEGENERACIJA (nema C_E)

nadomjesna shema





$$u_{ce} = -i_c (R_T \| R_c) - i_c \cdot R_E = -i_c (R_E + R_T \| R_c)$$

$$\underbrace{(u_{ce} - U_{ceq})}_{\Delta u_{ce}} = -\underbrace{(i_c - I_{cq})}_{\Delta i_c} (R_E + R_T \| R_c) \quad (1)$$

(1) $i_c = \emptyset$: $\quad u_{ce} = U_{ceq} + I_{cq}(R_E + R_T \| R_c) = 4{,}427 + 2{,}734 \cdot 10^{-3} \left(370 + \frac{10^3 \cdot 1{,}8 \cdot 10^3}{10^3 + 1{,}8 \cdot 10^3}\right)$

$u_{ce} = 8{,}837\,V$ //

$u_{ce} = \emptyset$: $\quad -U_{ceq} = -i_c (R_E + R_T \| R_c) + I_{cq}(R_E + R_T \| R_c)$

$$i_c = I_{cq} + \frac{U_{ceq}}{R_E + R_T \| R_c} = 2{,}734\,mA + \frac{4{,}427}{370 + \frac{10^3 \cdot 1{,}8 \cdot 10^3}{(10^3 + 1{,}8) \cdot 10^3}} = 5{,}479\,mA$$ //

} DRT

$\Delta u_{CE} = u_{ce} - U_{ceq} = 8{,}837 - 4{,}427 = 4{,}41\,V$ //

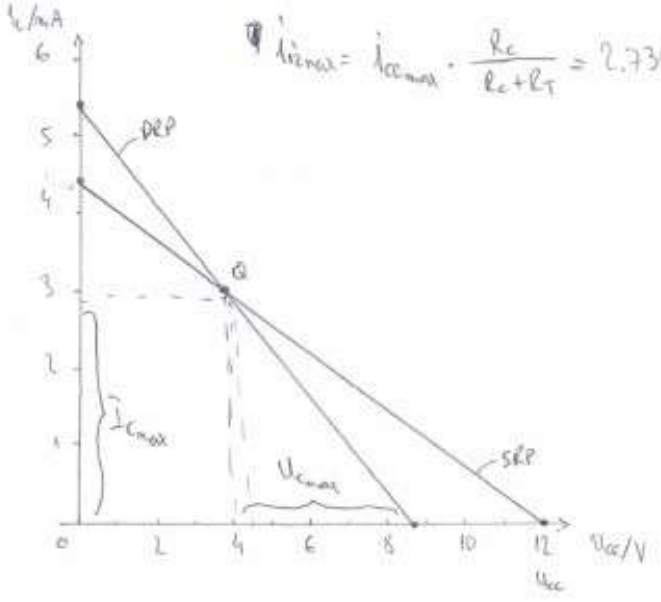
$\Delta i_c = i_c - I_{cq} = 5{,}479 - 2{,}734 = 2{,}745\,mA$ //

$U_{ce_{max}} = \min(\Delta u_{ce}, U_{ceq}) = \min(4{,}41, 4{,}427) = 4{,}41\,V$ //

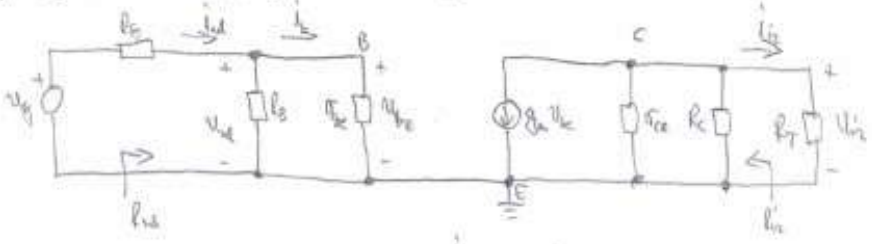
$u_{ce_{max}} = u_{iz_{max}} = 4{,}41\,V$ //

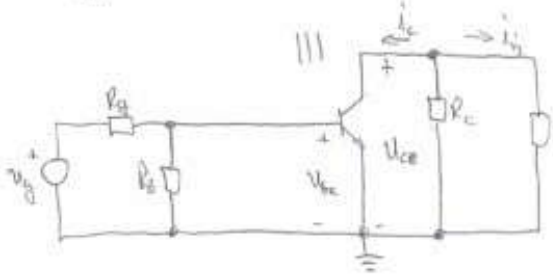
$i_{c_{max}} = \min(I_{cq}, \Delta i_c) = \min(2{,}734, 2{,}745) = 2{,}734\,mA$ //

$i_{iz_{max}} = i_{cc_{max}} \cdot \frac{R_c}{R_c + R_T} = 2{,}734 \cdot 10^{-3} \cdot \frac{1{,}8 \cdot 10^3}{2{,}8 \cdot 10^3} = 1{,}758\,mA$ //



b) $C_E = \infty \Rightarrow X_C = \emptyset \rightarrow$ ZAJEDNIČKI EMITER





$$u_{ce} = -i_c (R_c \| R_T)$$

$$\underbrace{(u_{ce} - U_{CEQ})}_{\Delta u_{ce}} = -\underbrace{(i_c - I_{cq})}_{\Delta i_c} (R_c \| R_T) \quad (*)$$

(*) $u_{ce} = \emptyset$: $\quad -U_{CEQ} = -I_c (R_c \| R_T) + I_{cq} (R_c \| R_T)$

$$i_c = I_{cq} + \frac{U_{CEQ}}{R_c \| R_T} = 2{,}734 \cdot 10^{-3} + \frac{4{,}427}{1{,}8 \cdot 10^3 \| 10^3} = 9{,}62 \text{ mA} //$$

$i_c = \emptyset$: $\quad u_{ce} = U_{CEQ} + I_{cq} (R_c \| R_T) = 4{,}427 + 2{,}734 \cdot 10^{-3} \cdot \frac{4500}{7} = 6{,}185 \text{ V} //$

} DRT

$\Delta u_{ce} = u_{ce} - U_{CEQ} = 6{,}185 - 4{,}427 = 1{,}758 \text{ V} //$

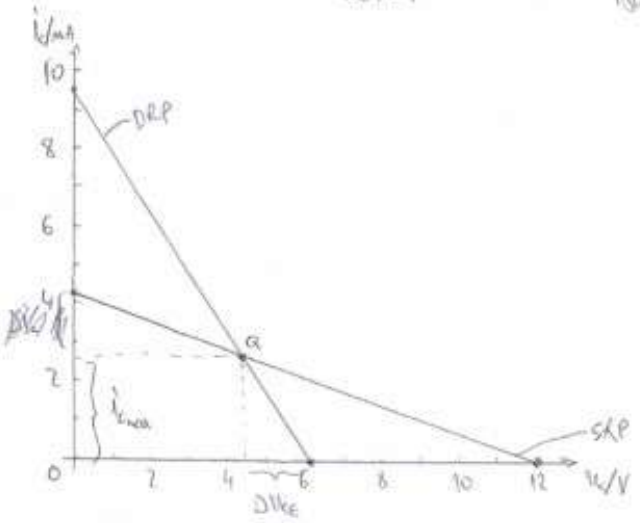
$\Delta i_c = i_c - I_{cq} = 9{,}62 - 2{,}734 = 6{,}886 \text{ mA} //$

$U_{CE_{max}} = \min(\Delta u_{ce}, U_{CEQ}) = \min(1{,}758, 4{,}427) = 1{,}758 \text{ V}$

$U_{CE_{max}} = u_{ce_{max}} = 1{,}758 \text{ V}$

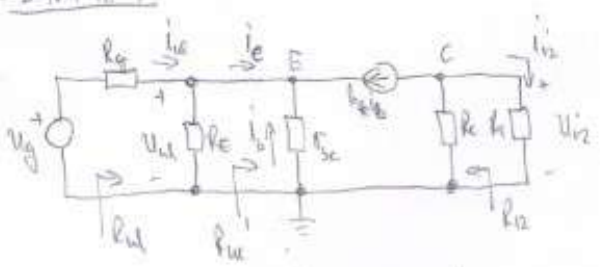
$i_{c_{max}} = \min(\Delta i_c, I_{cq}) = \min(6{,}886, 2{,}734) = 2{,}734 \text{ mA}$

$i_{ce_{max}} = i_{c_{max}} \cdot \frac{R_c}{R_c + R_T} = 2{,}734 \cdot 10^{-3} \cdot \frac{1800}{1800 + 1000} = 1{,}758 \text{ mA} //$



Prostor za rješavanje:

(4) o DINAMIKA - SZB



$R_{ul}' = \frac{U_{ul}}{i_e} = \frac{-i_b \cdot r_{be}}{-(h_{fe} i_b + i_b)} = \frac{i_b \cdot r_{be}}{i_b (1+h_{fe})} = 9.366\,\Omega$

$R_{ul} = \frac{U_{ul}}{i_{ul}} = R_E \| R_{ul}' = R_E \| \frac{r_{be}}{1+h_{fe}} = 9.28\,\Omega$ //

$A_V = \frac{U_{iz}}{U_{ul}} = \frac{-h_{fe} i_b \cdot \frac{R_c}{R_c + R_T} \cdot R_T}{-i_b \cdot r_{be}} = \frac{R_c \| R_T}{r_{be}} = 0.68$ //

$A_I = \frac{i_{iz}}{i_{ul}} = \frac{-h_{fe} i_b \cdot \frac{R_c}{R_c+R_T}}{-(1+h_{fe}) i_b \cdot \frac{R_E}{R_E + R_{ul}'}} = \frac{h_{fe}}{1+h_{fe}} \cdot \frac{R_c}{R_c+R_T} \cdot \frac{R_E}{R_E + R_{ul}'}$

$A_I = 0.63$ //

$A_{Vg} = A_V \cdot \frac{R_{ul}}{R_g + R_{ul}} = 0.62$ //

$R_{iz} = R_c = 1.8\,k\Omega$ //

$i_e = i_{ul} \cdot \frac{R_E}{R_E + R_{ul}'}$ $\quad i_e = -(1+h_{fe}) i_b$

$i_{ul} = i_e \cdot \frac{R_E + R_{ul}'}{R_E}$

$i_{ul} = -(1+h_{fe}) i_b \frac{R_E + R_{ul}'}{R_E}$

Tablica 1. Brojčani rezultati zadataka za pripremu

SZE						
	Maks. hod	R_{ul}	A_V	A_I	A_{Vg}	R_{iz}
$R_T = 1\,k\Omega$ $C_E = 0$	4,41V	2298Ω	-0,65	-1,49	-0,453	1800Ω
$R_T = 1\,k\Omega$ $C_E = \infty$	1,758V	675Ω	-67,96	-45,87	-27,39	1,8kΩ

SZB				
R_{ul}	A_V	A_I	A_{Vg}	R_{iz}
9,28Ω	0,68	0,63	0,62	1800Ω