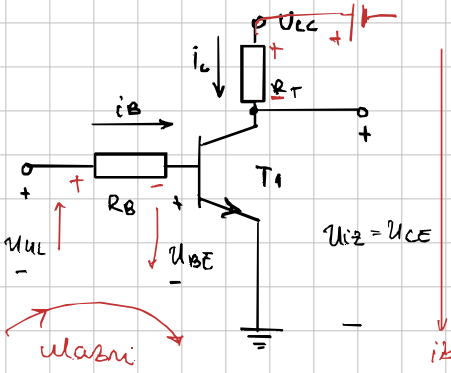
8.1. Osnovni sklop bipolarnog tranzistora



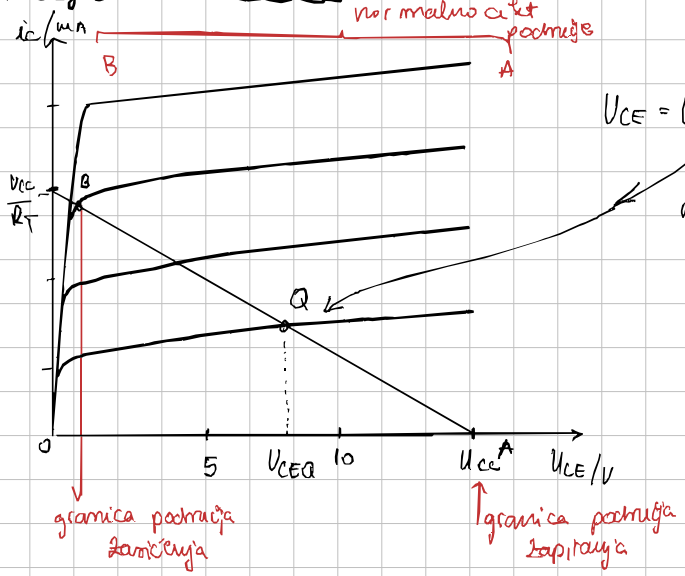
Ulazni krug:

$u_{UL} = R_B \cdot i_B + U_{BE}$

Izlazni krug:

$u_{iz} = u_{CE} = U_{CC} - R_T \cdot i_C$

Polje izlaznih kar.



$U_{CE} = U_{CC} - R_T \cdot i_C$ jednadžba radnog pravca

Naponska prijenosna kar:

$u_{iz} = f(u_{UL})$

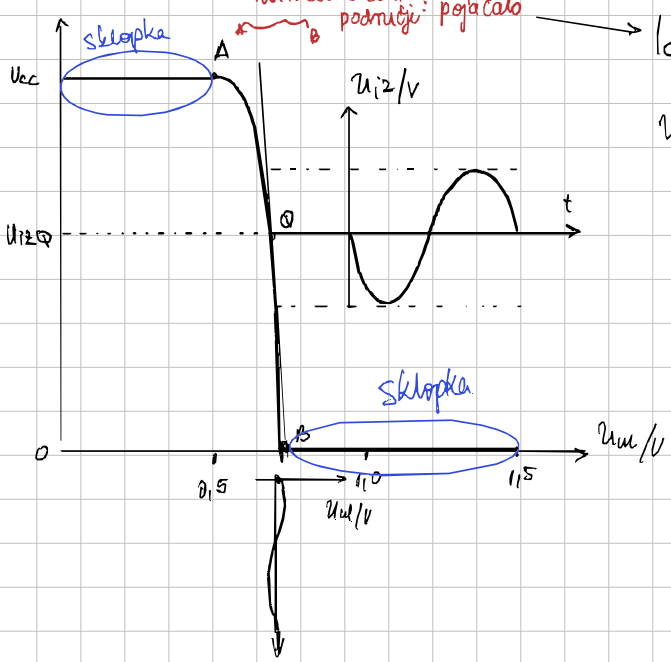
normalno akt. područje: pojačalo

$$I_C = I_S \exp\left(\frac{U_{BE}}{U_T}\right) \approx I_S \exp\left(\frac{u_{UL}}{U_T}\right)$$

$$u_{iz} = U_{CC} - R_T \cdot I_S \cdot \exp\left(\frac{u_{UL}}{U_T}\right)$$

Za $u_{UL} < 0{,}5\,V \rightarrow i_C \approx 0$

$u_{UL} = U_{BE} = U_{CC}$



Pojačanja

grafičko očitanje: $A_V = \frac{u_{iz}}{u_{ul}} = \frac{-U_{izm}\cdot \sin\omega t}{U_{ulm}\cdot \sin\omega t} = \frac{-U_{izm}}{U_{ulm}} \dots = \frac{-1.88}{8\cdot 10^{-3}} = -235$

↳ nagib krivulje

↕ naponsko

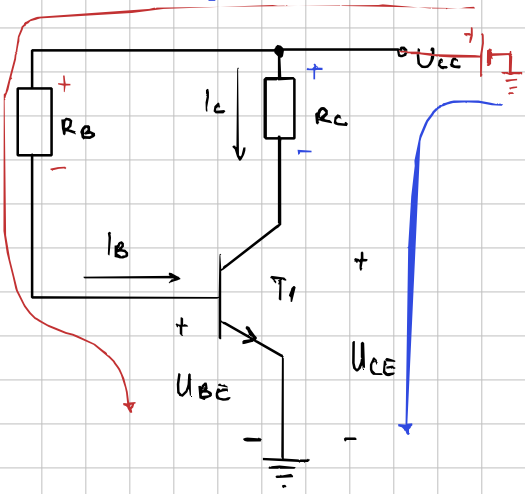
analitički izvod: $A_V = \left.\frac{du_{iz}}{du_{ul}}\right|_Q \approx \left.-\frac{R_T}{U_T} I_S \cdot \exp\left(\frac{u_{ul}}{U_T}\right)\right|_Q \approx -\frac{R_T \cdot I_{CQ}}{U_T} = -g_m R_T$ (u SRT)

nagib krivulje

strujno pojačanje:

$A_I = \left.\frac{di_z}{di_{ul}}\right|_Q = -\left.\frac{di_C}{di_B}\right|_Q = -h_{fe}$ → $h_{fe} \approx 100$ → $A_I \approx -100$

Podešavanje radne točke



Ulazni strujni krug:

$-U_{CC} + R_B \cdot I_{BQ} + U_{BEQ} = 0$

↳ $U_{CC} - U_{BEQ} = R_B \cdot I_{BQ}$

$\Rightarrow I_{BQ} = \frac{U_{CC} - U_{BEQ}}{R_B}$

$U_{BEQ} \approx U_\gamma$ (napon kolena)

Izlazni strujni krug

$-U_{CC} + R_C \cdot I_C + U_{CEQ} = 0$

$U_{CEQ} = U_{CC} - R_C \cdot I_C$

$I_{CQ} \approx \beta \cdot I_{BQ}$

Normalno aktivno područje

$U_{CEQ} > U_{BEQ}$

Primjer 8.1.)

Shema ovog izlaza

$U_{CC} = 15V$

$R_C = 2k\Omega$

$U_\gamma = 0{,}7V$

$\beta = 100$

$R_B = ?$

$U_{CEQ} = \frac{U_{CC}}{2}$

↳ $U_{CEQ} = 7.5V$

$U_{BEQ} \approx U_\gamma$

→ $U_{BEQ} = 0{,}7V$

normalno aktivno područje?

↳ $U_{CEQ} \gtrless U_{BEQ}$

$7.5V > 0.7V$ ✓ NAP

R_B → ulazni strujni krug

$I_{CQ} = \frac{U_{CC} - U_{CEQ}}{R_C} = \frac{15 - 7.5}{2000}$ → $I_{CQ} = 3{,}75mA$

$I_{CQ} \approx \beta \cdot I_{BQ}$ → $I_{BQ} = \frac{I_{CQ}}{\beta} = \frac{U_{CC} - U_{BEQ}}{R_B}$ → $R_B = \beta \cdot \frac{U_{CC} - U_{BEQ}}{I_{CQ}}$

$I_{BQ} = 3{,}75 \times 10^{-5} A$

$R_B = 381 k\Omega$

Primjer 8.2) → u prošlom primjeru naraste temp s 25° na 75°

$\beta_1 (25°) = 100 \longrightarrow \beta_2 (75°) = 150$

$I_{BQ}, I_{CQ} = ?$ *zanemari I_{CEO}, U_{BE} se ne mijenja s promjenom temperature

$U_{BEQ}, U_{CEQ} = ?$

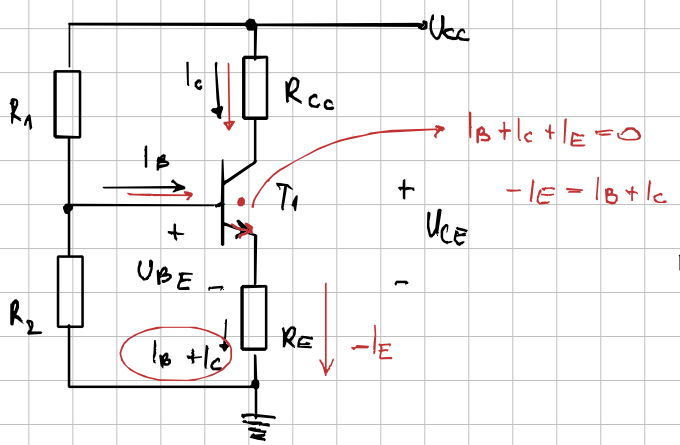
→ U_{BEQ} = konst. → jednadžba ulazne strujne krivulje ostaje ista

↳ $I_{BQ_1} = I_{BQ_2} = 37{,}5\,\mu A$

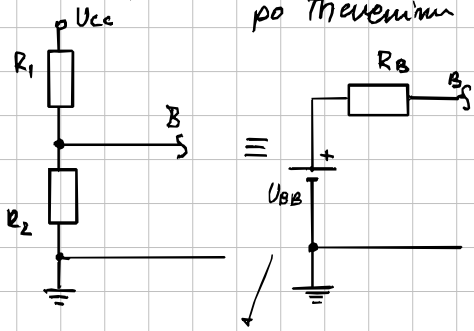
$I_{CQ_2} = \beta_2 \cdot I_{BQ_2} = \beta_2 \cdot I_{BQ_1} \longrightarrow I_{CQ_2} = 5{,}63\,mA$ ↑ +50%

$U_{CEQ} = U_{CC} - I_{CQ_2} \cdot R_C \longrightarrow U_{CEQ} = 3.84\,V$ ↓ − 50%

Stabilizacija radne točke Emiterskim otpornikom



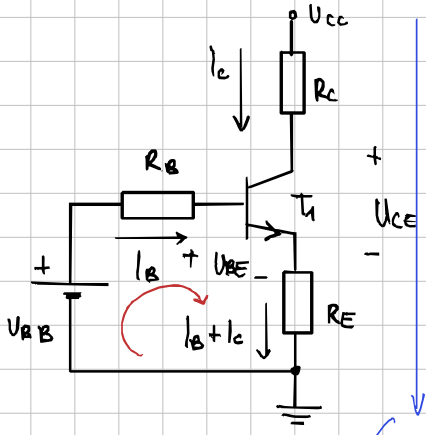
Nadomještanje otporog djelila po Theveninu



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

$R_B = R_1 \parallel R_2$

Shema sklopa za statičku analizu



$-U_{BB} + R_B \cdot I_B + U_{BE} + R_E \cdot (I_B + I_C) = 0$

▸ u statičkoj radnoj točki

$I_{CQ} = \beta \cdot I_{BQ}$

$U_{BB} = R_B \cdot I_B + U_{BEQ} + R_E \cdot I_{BQ}(1+\beta)$

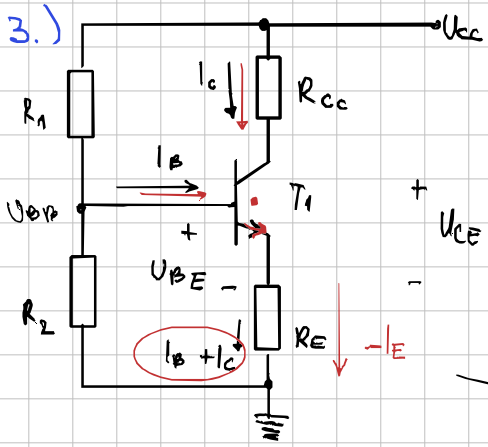
$\Rightarrow I_{BQ} = \frac{U_{BB} - U_{BEQ}}{R_B + (1+\beta) \cdot R_E} = \frac{U_{BB} - U_\gamma}{R_B + (1+\beta) R_E}$

$U_{CEQ} = U_{CC} - R_C \cdot I_{CQ} - R_E (I_{BQ} + I_{CQ})$

// zanemari

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

Primjer 8.3.)



$V_{CC} = 15V$

$R_1 = 11k\Omega$

$R_2 = 2k\Omega$

$R_C = 2k\Omega$

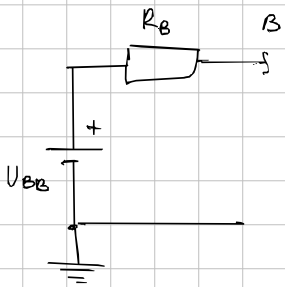
$R_E = 500\Omega$

a) $I_E, I_C = ?$

$U_{BEQ}, U_{CEQ} = ?$

$t = 25°$

$U_\gamma = 0,7V, \quad \beta = 100$



$U_{BB} = \frac{R_2}{R_1 + R_2} \cdot V_{CC}$ * kao kod unipolarnih tranz.

$U_{BB} = 2,31V$

$R_B = R_1 \| R_2 = \frac{R_1 R_2}{R_1 + R_2} = 1,69k\Omega$

$U_{BEQ} = U_\gamma = 0,7V$

$I_{BQ_1} = \frac{U_{BB} - U_{BEQ}}{R_B + (1+\beta) \cdot R_E} = \frac{U_{BB} - U_\gamma}{R_B + (1+\beta) \cdot R_E} = \frac{2,31 - 0,7}{1,69 \cdot 10^3 + (1+100) \cdot 500}$

$I_{BQ_1} = 30,8\mu A \longrightarrow I_{CQ_1} = \beta \cdot I_{BQ_1}$

$I_{CQ_1} = 3,08mA$

$I_{EQ} = -(I_{BQ_1} + I_{CQ_1})$

$I_{EQ} = -3,11mA$

$\Rightarrow U_{CEQ} = V_{CC} - (R_C + R_E) \cdot I_{CQ}$

$U_{CEQ} = 7,3V$

b) $75°C \longrightarrow \beta_2 = 150$

$U_{BEQ_2} = U_{BEQ_1} = 0,7 \longrightarrow$

$U_{BB} = 2,31V$

$I_{BQ_1} = \frac{U_{BB} - U_\gamma}{R_B + (1+\beta) \cdot R_E} \longrightarrow \boxed{I_{BQ} = 21,32\mu A}$

$I_{CQ_2} = \beta \cdot I_{BQ_2} \longrightarrow \boxed{I_{CQ_2} = 3,2\ mA}$

$I_{EQ_2} = -(I_{BQ_2} + I_{CQ_2})$

$\boxed{I_{EQ_2} = -3,22\ mA}$

$\Rightarrow U_{CEQ} = V_{CC} - (R_C + R_E) \cdot I_{CQ}$

$\boxed{U_{CEQ} = 7,0V}$

Uvjet za dobru stabilizaciju statičke radne točke

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

⟹ onda kada je $\boxed{I_{CQ}}$ neovisna o β uz $R_B \ll (1+\beta) R_E$

↳ R_B zanemarivo

↳ također zanemarivo

pojednostavljeno

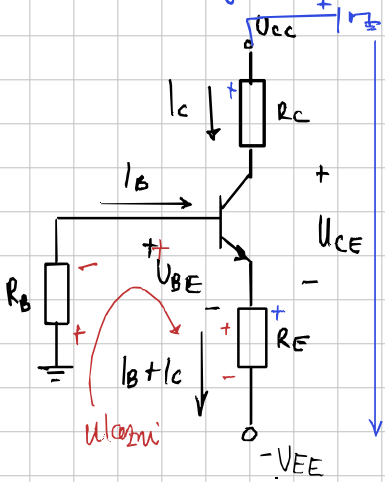
$$\hookrightarrow I_{CQ} \approx \frac{\beta (U_{BB} - U_{BEQ})}{\beta \cdot R_E}$$

$$\Longrightarrow I_{CQ} \approx \frac{U_{BB} - U_{BEQ}}{R_E}$$

$\boxed{U_{BB}}$ → $U_{BB} \approx U_{BE} + R_E \cdot I_C$

#2. način podešavanja radne točke

→ Podešavanje radne točke s dva napona napajanja



jednadžba ulaznog strujnog kruga

$$R_B \cdot I_B + U_{BE} + R_E (I_B + I_C) - U_{EE} = 0$$

$$U_{EE} = R_B \cdot I_B + U_{BE} + R_E (I_B + I_C)$$

→ uz $I_C = \beta \cdot I_B$

$$I_B = \frac{U_{EE} - U_{BE}}{R_B + (1+\beta) \cdot R_E}$$

jednadžba izlaznog strujnog kruga

$$-U_{CC} + R_C \cdot I_C + U_{CE} + R_E I_C - U_{EE} = 0$$

$$U_{CE} = U_{CC} + U_{EE} - (R_C + R_E) I_C$$