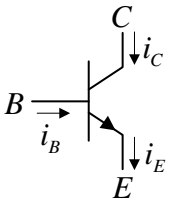
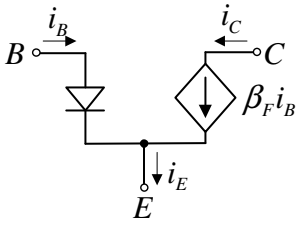
Režimi rada bipolarnog tranzistora

- NPN tranzistor



$$i_E = i_B + i_C$$

  - Direktni aktivni režim (DAR):



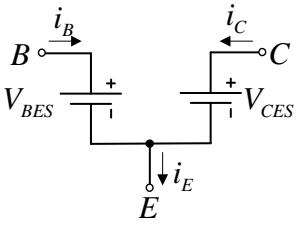
$$i_B > 0, i_C > 0, i_E > 0$$

$$i_C = \beta_F i_B$$

$$v_{BE} = V_{BE}$$

$$v_{CE} > V_{CES}$$

  - Zasićenje:

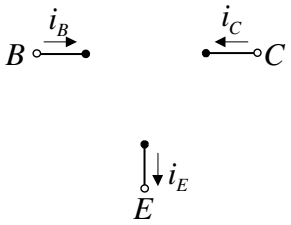


$$i_C < \beta_F i_B$$

$$v_{BE} = V_{BES}$$

$$v_{CE} = V_{CES}$$

  - Zakočenje (OFF):

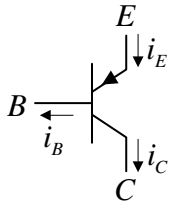


$$i_B = 0, i_C = 0, i_E = 0$$

$$v_{BE} < V_\gamma$$

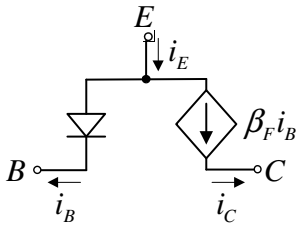
  - Inverzni aktivni režim

- PNP tranzistor



$$i_E = i_B + i_C$$

- Direktni aktivni režim (DAR):



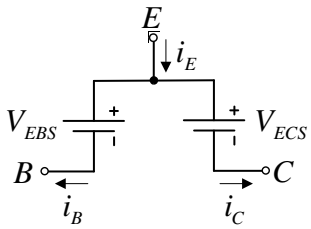
$$i_B > 0, i_C > 0, i_E > 0$$

$$i_C = \beta_F i_B$$

$$v_{EB} = V_{EB}$$

$$v_{EC} > V_{ECS}$$

- Zasićenje:



$$i_C < \beta_F i_B$$

$$v_{EB} = V_{EBS}$$

$$v_{EC} = V_{ECS}$$

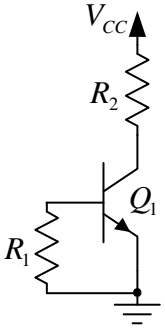
- Zakočenje (OFF):

$$i_B = 0, i_C = 0, i_E = 0$$

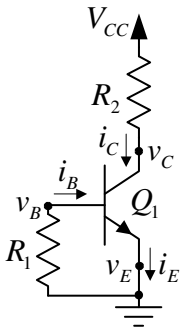
$$v_{EB} < V_\gamma$$

- Inverzni aktivni režim

74. Za kolo sa slike je poznato: $V_\gamma = V_{BE} = 0{,}6\text{V}$, $V_{BES} = 0{,}6\text{V}$, $V_{CES} = 0{,}2\text{V}$, $\beta_F = 100$, $V_{CC} = 12\text{V}$, $R_1 = 10\text{k}\Omega$ i $R_2 = 1\text{k}\Omega$. Odrediti režim rada tranzistora Q_1, kao i napone i struje svih priključaka tranzistora Q_1.



Rešenje:



Pretpostavka Q_1-OFF:

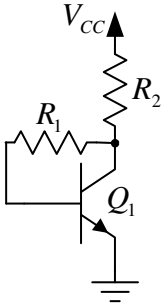
provera: $v_{BE} < V_\gamma$?

$i_C = 0, i_E = 0, i_B = 0 \Rightarrow v_B = 0$
$v_E = 0$
$\Rightarrow v_{BE} = 0 < V_\gamma \Rightarrow$ pretpostavka je tačna, tj. Q_1 je zakočen

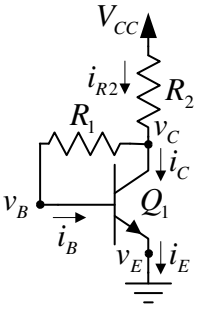
$\boxed{i_B = 0}$ $\boxed{i_C = 0}$ $\boxed{i_E = 0}$

$\boxed{v_B = 0}$ $\boxed{v_E = 0}$ $v_C = V_{CC} \Rightarrow \boxed{v_C = 12\text{V}}$

75. Za kolo sa slike je poznato: $V_\gamma = V_{BE} = 0{,}7\text{V}$, $V_{BES} = 0{,}7\text{V}$, $V_{CES} = 0{,}2\text{V}$, $\beta_F = 75$, $V_{CC} = 10\text{V}$, $R_1 = 5\text{k}\Omega$ i $R_2 = 1{,}2\text{k}\Omega$. Odrediti režim rada tranzistora Q_1, kao i napone i struje svih priključaka tranzistora Q_1.



Rešenje:



Pretpostavka Q_1-OFF:

provera: $v_{BE} < V_\gamma$?

$i_C = 0, i_E = 0, i_B = 0 \Rightarrow i_{R2} = 0 \Rightarrow v_B = V_{CC}$
$v_E = 0$
$\Rightarrow v_{BE} = V_{CC} > V_\gamma \Rightarrow$
loša pretpostavka

Pretpostavka Q_1-DAR:

provera: $v_{CE} > V_{CES}$?

$V_{CC} - R_2 i_{R2} - R_1 i_B - V_{BE} = 0 \quad \Rightarrow \quad V_{CC} - R_2(i_B + i_C) - R_1 i_B - V_{BE} = 0 \quad \Rightarrow$

$V_{CC} - R_2(\beta_F + 1) i_B - R_1 i_B - V_{BE} = 0 \quad \Rightarrow \quad i_B = \dfrac{V_{CC} - V_{BE}}{R_2(\beta_F + 1) + R_1} = 96{,}67\mu\text{A}$

$v_{CE} = (V_{CC} - R_2 i_{R2}) - 0 = V_{CC} - R_2(i_B + i_C) = V_{CC} - R_2(\beta_F + 1) i_B = 1{,}18\text{V} > V_{CES} \quad \Rightarrow$

pretpostavka je tačna, tj. $\boxed{Q_1 \text{ je u DAR-u}}$

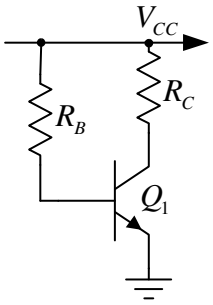
$\boxed{i_B = 96{,}67\mu\text{A}}$ $\qquad i_C = \beta_F i_B \quad \Rightarrow \quad \boxed{i_C = 7{,}25\text{mA}}$

$i_E = (\beta_F + 1) i_B \quad \Rightarrow \quad \boxed{i_E = 7{,}35\text{mA}}$

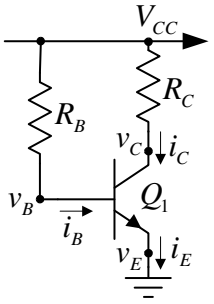
$v_C = V_{CC} - R_2 i_{R2} = V_{CC} - R_2(i_B + i_C) = V_{CC} - R_2(\beta_F + 1) i_B \quad \Rightarrow \quad \boxed{v_C = 1{,}18\text{V}}$

$v_B = V_{BE} \quad \Rightarrow \quad \boxed{v_B = 0{,}7\text{V}}$ $\qquad \boxed{v_E = 0}$

76. Za kolo sa slike je poznato: $V_\gamma = V_{BE} = 0{,}6\text{V}$, $V_{BES} = 0{,}6\text{V}$, $V_{CES} = 0{,}2\text{V}$, $\beta_F = 100$, $V_{CC} = 3\text{V}$, $R_B = 20\text{k}\Omega$ i $R_C = 10\text{k}\Omega$. Odrediti režim rada tranzistora Q_1, kao i napone i struje svih priključaka tranzistora Q_1.



<u>Rešenje:</u>



Pretpostavka Q_1-OFF:

provera: $v_{BE} < V_\gamma$?

$\left.\begin{array}{l} i_C = 0,\ i_E = 0,\ i_B = 0 \quad \Rightarrow \quad v_B = V_{CC} \\ v_E = 0 \end{array}\right\} \quad \Rightarrow \quad v_{BE} = V_{CC} > V_\gamma \quad \Rightarrow$ loša pretpostavka

Pretpostavka Q_1-DAR:

provera: $v_{CE} > V_{CES}$?

$$v_{CE} = v_C - v_E = V_{CC} - R_C i_C = V_{CC} - R_C \beta_F i_B = V_{CC} - R_C \beta_F \frac{V_{CC} - V_{BE}}{R_B} = -117\text{V} < V_{CES} \quad \Rightarrow \quad \text{loša pretpostavka}$$

Pretpostavka Q_1-zasićenje:

provera: $\beta_F i_B > i_C$?

$$\left.\begin{aligned} \beta_F i_B &= \beta_F \frac{V_{CC} - V_{BES}}{R_B} = 12\text{mA} \\ i_C &= \frac{V_{CC} - V_{CES}}{R_C} = 0{,}28\text{mA} \end{aligned}\right\} \Rightarrow \beta_F i_B > i_C \quad \Rightarrow \quad \text{pretpostavka je tačna, tj. } \boxed{Q_1 \text{ je u zasićenju}}$$

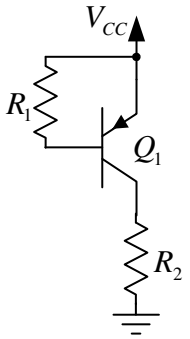
$$i_B = \frac{V_{CC} - V_{BES}}{R_B} \quad \Rightarrow \quad \boxed{i_B = 120\mu\text{A}} \qquad \boxed{i_C = 280\mu\text{A}}$$

$$i_E = i_B + i_C \quad \Rightarrow \quad \boxed{i_E = 400\mu\text{A}}$$

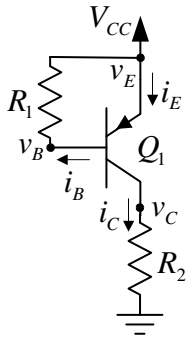
$$v_C = V_{CES} \quad \Rightarrow \quad \boxed{v_C = 0{,}2\text{V}}$$

$$v_B = V_{BES} \quad \Rightarrow \quad \boxed{v_B = 0{,}6\text{V}} \qquad \boxed{v_E = 0}$$

77. Za kolo sa slike je poznato: $V_\gamma = V_{EB} = 0{,}6\text{V}$, $V_{EBS} = 0{,}6\text{V}$, $V_{ECS} = 0{,}2\text{V}$, $\beta_F = 100$, $V_{CC} = 12\text{V}$, $R_1 = 10\text{k}\Omega$ i $R_2 = 1\text{k}\Omega$. Odrediti režim rada tranzistora Q_1, kao i napone i struje svih priključaka tranzistora Q_1.



Rešenje:



Pretpostavka Q_1-OFF:

provera: $v_{EB} < V_\gamma$?

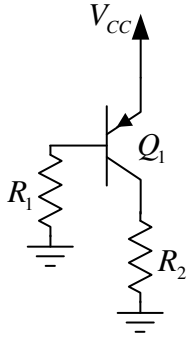
$$\left.\begin{array}{l} v_E = V_{CC} \\ i_C = 0,\ i_E = 0,\ i_B = 0 \quad \Rightarrow \quad v_B = V_{CC} \end{array}\right\} \quad \Rightarrow \quad v_{EB} = 0 < V_\gamma \quad \Rightarrow$$

pretpostavka je tačna, tj. Q_1 je zakočen

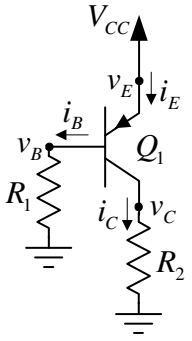
$\boxed{i_B = 0}$ $\boxed{i_C = 0}$ $\boxed{i_E = 0}$

$\boxed{v_C = 0}$ $\boxed{v_E = 12\text{V}}$ $\boxed{v_B = 12\text{V}}$

78. Za kolo sa slike je poznato: $V_\gamma = V_{EB} = 0{,}6\text{V}$, $V_{EBS} = 0{,}6\text{V}$, $V_{ECS} = 0{,}2\text{V}$, $\beta_F = 100$, $V_{CC} = 12\text{V}$, $R_1 = 200\text{k}\Omega$ i $R_2 = 1\text{k}\Omega$. Odrediti režim rada tranzistora Q_1, kao i napone i struje svih priključaka tranzistora Q_1.



Rešenje:



Pretpostavka Q_1-OFF:

provera: $v_{EB} < V_\gamma$?

$$\left.\begin{array}{l} v_E = V_{CC} \\ i_C = 0,\ i_E = 0,\ i_B = 0 \quad \Rightarrow \quad v_B = 0 \end{array}\right\} \quad \Rightarrow \quad v_{EB} = V_{CC} > V_\gamma \quad \Rightarrow$$

loša pretpostavka

Pretpostavka Q_1-DAR:

provera: $v_{EC} > V_{ECS}$?

$$v_{EC} = v_E - v_C = V_{CC} - R_2 i_C = V_{CC} - R_2 \beta_F i_B = V_{CC} - R_2 \beta_F \frac{V_{CC} - V_{EB}}{R_1} = 6{,}3\text{V} > V_{ECS} \quad \Rightarrow$$

pretpostavka je tačna, tj. $\boxed{Q_1 \text{ je u DAR-u}}$

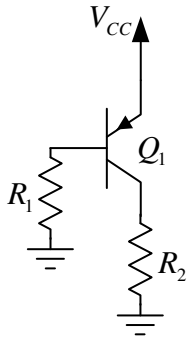
$$i_B = \frac{V_{CC} - V_{EB}}{R_1} \quad \Rightarrow \quad \boxed{i_B = 57\mu\text{A}} \qquad i_C = \beta_F i_B \quad \Rightarrow \quad \boxed{i_C = 5{,}7\text{mA}}$$

$$i_E = (\beta_F + 1) i_B \quad \Rightarrow \quad \boxed{i_E = 5{,}76\text{mA}}$$

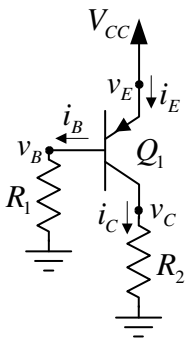
$$v_C = R_2 i_C \quad \Rightarrow \quad \boxed{v_C = 5{,}7\text{V}}$$

$$v_B = V_{CC} - V_{EB} \quad \Rightarrow \quad \boxed{v_B = 11{,}4\text{V}} \qquad v_E = V_{CC} \quad \Rightarrow \quad \boxed{v_E = 12\text{V}}$$

79. Za kolo sa slike je poznato: $V_\gamma = V_{EB} = 0{,}6\text{V}$, $V_{EBS} = 0{,}6\text{V}$, $V_{ECS} = 0{,}2\text{V}$, $\beta_F = 100$, $V_{CC} = 12\text{V}$, $R_1 = 10\text{k}\Omega$ i $R_2 = 1\text{k}\Omega$. Odrediti režim rada tranzistora Q_1, kao i napone i struje svih priključaka tranzistora Q_1.



<u>Rešenje:</u>



Pretpostavka Q_1-OFF:

provera: $v_{EB} < V_\gamma$?

$$\left.\begin{array}{l} v_E = V_{CC} \\ i_C = 0,\ i_E = 0,\ i_B = 0 \quad \Rightarrow \quad v_B = 0 \end{array}\right\} \quad \Rightarrow \quad v_{EB} = V_{CC} > V_\gamma \quad \Rightarrow \quad \text{loša pretpostavka}$$

Pretpostavka Q_1-DAR:

provera: $v_{EC} > V_{ECS}$?

$$v_{EC} = v_E - v_C = V_{CC} - R_2 i_C = V_{CC} - R_2 \beta_F i_B = V_{CC} - R_2 \beta_F \frac{V_{CC} - V_{EB}}{R_1} = -102\text{V} < V_{ECS} \quad \Rightarrow \quad \text{loša}$$

pretpostavka

Pretpostavka Q_1-zasićenje:

provera: $\beta_F i_B > i_C$?

$$\left.\begin{aligned} \beta_F i_B &= \beta_F \frac{V_{CC} - V_{EBS}}{R_1} = 114\text{mA} \\ i_C &= \frac{V_{CC} - V_{ECS}}{R_2} = 11{,}8\text{mA} \end{aligned}\right\} \Rightarrow \beta_F i_B > i_C \quad \Rightarrow \quad \text{pretpostavka je tačna, tj. } \boxed{Q_1 \text{ je u zasićenju}}$$

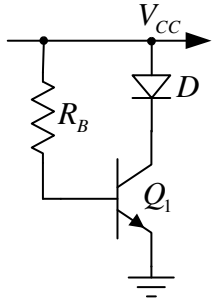
$$i_B = \frac{V_{CC} - V_{EBS}}{R_1} \quad \Rightarrow \quad \boxed{i_B = 1{,}14\text{mA}} \qquad \boxed{i_C = 11{,}8\text{mA}}$$

$$i_E = i_B + i_C \quad \Rightarrow \quad \boxed{i_E = 12{,}94\text{mA}}$$

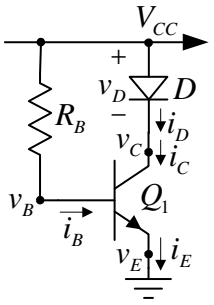
$$v_C = V_{CC} - V_{ECS} \quad \Rightarrow \quad \boxed{v_C = 11{,}8\text{V}}$$

$$v_B = V_{CC} - V_{EBS} \quad \Rightarrow \quad \boxed{v_B = 11{,}4\text{V}} \qquad v_E = V_{CC} \quad \Rightarrow \quad \boxed{v_E = 12\text{V}}$$

80. Za kolo sa slike je poznato: $V_\gamma = V_{BE} = 0{,}6\text{V}$, $V_{BES} = 0{,}6\text{V}$, $V_{CES} = 0{,}2\text{V}$, $\beta_F = 100$, $V_{CC} = 3\text{V}$ i $R_B = 20\text{k}\Omega$. Dioda D je idealna sa parametrom $V_D = 0{,}6\text{V}$ Odrediti režime rada tranzistora Q_1 i diode D, kao i napone i struje svih priključaka tranzistora Q_1.



Rešenje:



Pretpostavka Q_1-OFF i D-OFF:

provera: $v_{BE} < V_\gamma$? (jer ako se dokaže da je Q_1-OFF to će značiti i da je dioda sigurno isključena, jer iz $i_C = 0 \;\Rightarrow\; i_D = 0$)

$$\left.\begin{array}{l} i_C = 0,\, i_E = 0,\, i_B = 0 \;\Rightarrow\; v_B = V_{CC} \\ v_E = 0 \end{array}\right\} \;\Rightarrow\; v_{BE} = V_{CC} > V_\gamma \;\Rightarrow\; \text{loša pretpostavka}$$

Pretpostavka Q_1-DAR i D-ON:

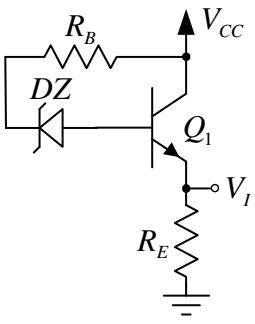
provera: $v_{CE} > V_{CES}$ i $i_D > 0$?

$$\left.\begin{array}{l} v_{CE} = v_C - v_E = (V_{CC} - V_D) - 0 = 2{,}4\text{V} > V_{CES} \\ i_D = i_C = \beta_F i_B = \beta_F \dfrac{V_{CC} - V_{BE}}{R_B} = 12\text{mA} > 0 \end{array}\right\} \;\Rightarrow\; \text{pretpostavka je tačna, tj. } \boxed{Q_1 \text{ je u DAR-u}} \text{ i } \boxed{D \text{ je ON}}$$

$$i_B = \frac{V_{CC} - V_{BE}}{R_B} \;\Rightarrow\; \boxed{i_B = 120\mu\text{A}} \qquad \boxed{i_C = 12\text{mA}} \qquad i_E = (\beta_F + 1) i_B \;\Rightarrow\; \boxed{i_E = 12{,}12\text{mA}}$$

$$v_C = V_{CC} - V_D \;\Rightarrow\; \boxed{v_C = 2{,}4\text{V}} \qquad v_B = V_{BE} \;\Rightarrow\; \boxed{v_B = 0{,}7\text{V}} \qquad \boxed{v_E = 0}$$

81. Za kolo sa slike je poznato: $V_\gamma = V_{BE} = 0{,}6\text{V}$, $V_{BES} = 0{,}6\text{V}$, $V_{CES} = 0{,}2\text{V}$, $\beta_F = 100$, $V_{CC} = 10\text{V}$, $R_B = 10\text{k}\Omega$ i $R_E = 100\Omega$. Zener dioda je idealna sa parametrima $V_D = 0$ i $V_Z = 3{,}2\text{V}$.

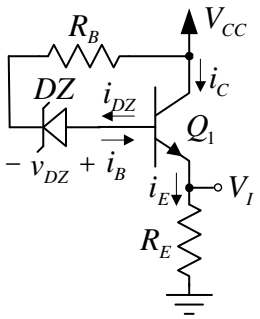


a) Izračunati izlazni napon V_I.

b) Izračunati kolika bi trebala da bude vrednost napona V_{CC} da bi tranzistor Q_1 bio na granici između direktnog aktivnog režima i zakočenja.

Rešenje:

a)



Q_1 neće biti OFF jer je razlika potencijala između V_{CC} i mase dovoljna da se obezbedi napon V_{BE} na spoju baza-emitor tranzistora Q_1 (uz odgovarajući pad napona na otpornicima R_B, R_E i Zener diodi DZ).

Pretpostavka Q_1-DAR i DZ-proboj:

provera: $v_{CE} > V_{CES}$ i $i_{DZ} < 0$?

$$V_{CC} - i_B R_B - V_Z - V_{BE} - i_E R_E = 0$$

$$V_{CC} - i_B R_B - V_Z - V_{BE} - (\beta_F + 1) i_B R_E = 0$$

$$\left.\begin{aligned} i_B &= \frac{V_{CC} - V_Z - V_{BE}}{R_B + (\beta_F + 1) R_E} = 308{,}5\mu\text{A} \quad \Rightarrow \quad i_{DZ} = -308{,}5\mu\text{A} < 0 \\ v_{CE} &= v_C - v_E = V_{CC} - (\beta_F + 1) i_B R_E = 6{,}88\text{V} > V_{CES} \end{aligned}\right\} \quad \Rightarrow$$

pretpostavka je tačna, tj. Q_1 je u DAR-u i DZ je u proboju.

$$V_I = v_E = i_E R_E = (\beta_F + 1) i_B R_E \quad \Rightarrow \quad \boxed{V_I = 3{,}12\text{V}}$$

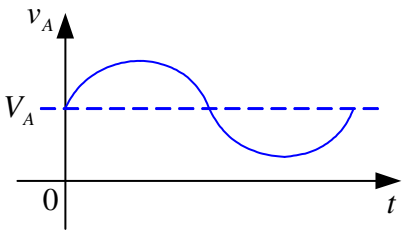
b) Smanjivanjem napona V_{CC} smanjivaće se razlika potencijala između V_{CC} i mase potrebna da bi se obezbedio napon V_{BE} na spoju baza-emitor tranzistora Q_1 (uz odgovarajući pad napona na otpornicima R_B, R_E i Zener diodi DZ).

Kada se napon V_{CC} smanji na vrednost $V_{CC\min} = V_Z + V_{BE}$, Zener dioda će biti na granici između proboja i zakočenja (i_{DZ} će pasti na nulu, a pritom će biti $v_{DZ} = -V_Z$), a tranzistor na granici između DAR-a i zakočenja (i_B, i_C i i_E će pasti na nulu, a pritom će biti $v_{BE} = V_{BE}$). Dakle:

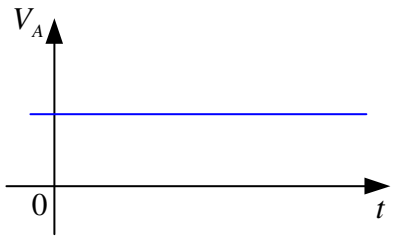
$$V_{CC\min} = V_Z + V_{BE} \quad \Rightarrow \quad \boxed{V_{CC\min} = 3{,}8\text{V}}$$

Pojačavači sa bipolarnim tranzistorima

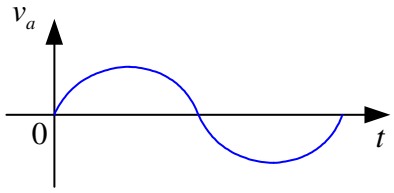
- Konvencija za obeležavanje signala (napona i struja) u kolu pojačavača
  - ukupan signal: v_A



  - jednosmerna komponenta signala (srednja vrednost signala): V_A

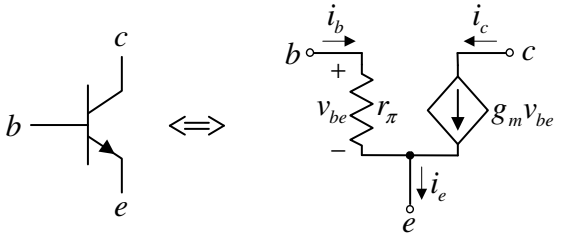


  - naizmenična komponenta signala (mali signal): v_a



  - $v_A = V_A + v_a$

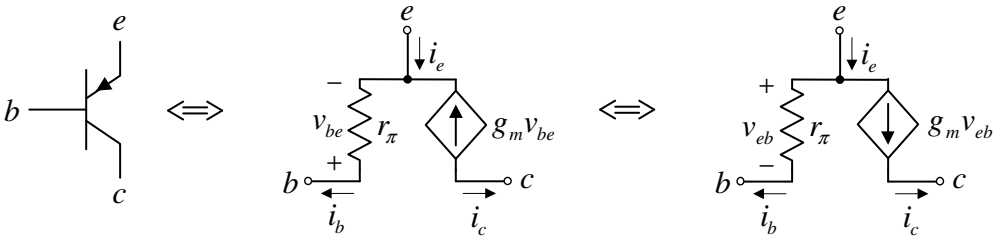
- Model NPN tranzistora za mali signal:



$$g_m = \frac{I_C}{V_t}; \qquad r_\pi = \frac{\beta_0}{g_m}$$

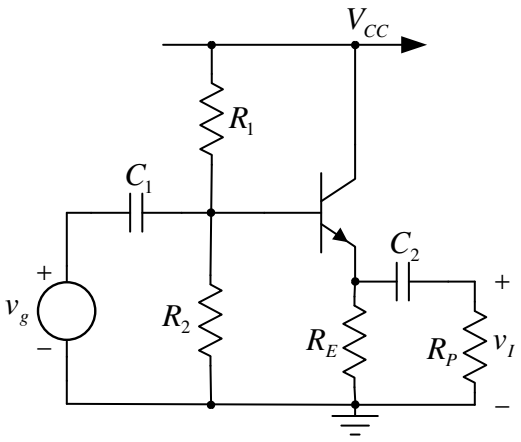
$$g_m v_{be} = g_m r_\pi i_b = \beta_0 i_b$$

- Model PNP tranzistora za mali signal:



$$g_m = \frac{I_C}{V_t}; \qquad r_\pi = \frac{\beta_0}{g_m}; \qquad g_m v_{eb} = g_m r_\pi i_b = \beta_0 i_b$$

82. Za pojačavač sa slike je poznato: $\beta_F = \beta_0 = 100$, $V_{BE} = 0{,}7\text{V}$, $V_t = 26\text{mV}$, $V_{CC} = 12\text{V}$, $C_1 \to \infty$, $C_2 \to \infty$, $R_1 = 19{,}5\,\text{k}\Omega$, $R_2 = 39\,\text{k}\Omega$, $R_E = 594\,\Omega$ i $R_P = 1\,\text{k}\Omega$.



a) Izračunati jednosmerne struje (I_B, I_C i I_E) i jednosmerne napone tranzistora (V_B, V_C i V_E).

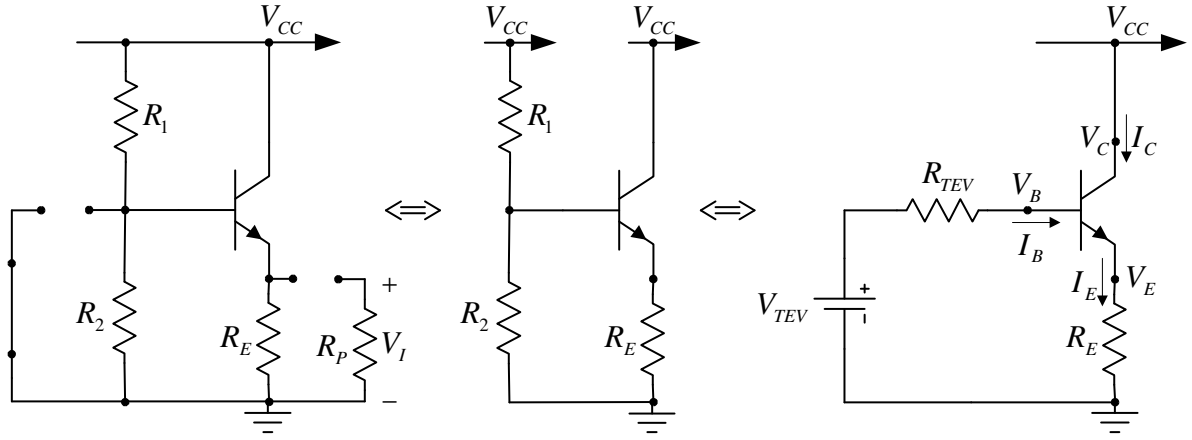
b) Izračunati naponsko pojačanje pojačavača $a_v = \frac{v_i}{v_g}$, ulaznu otpornost koju vidi generator naizmeničnog signala v_g i izlaznu otpornost koju vidi potrošač R_P.

Rešenje:

a) DC analiza:

Formiranje šeme za DC analizu:

- ukidanje svih naizmeničnih generatora;
- zamena kondenzatora otvorenim vezama.



$$V_{TEV} = \frac{R_2}{R_1 + R_2} V_{CC} = 8\text{V}\,; \qquad R_{TEV} = R_1 \parallel R_2 = \frac{R_1 R_2}{R_1 + R_2} = 13\text{k}\Omega\,;$$

Tranzistor je u DAR-u (preduslov da bi pojačavač ispravno radio)!

$$R_E I_E + V_{BE} + R_{TEV} I_B = V_{TEV}\,; \quad I_E = I_B(\beta_F + 1)\,;$$

$$I_B = \frac{V_{TEV} - V_{BE}}{R_{TEV} + (\beta_F + 1) R_E} \quad \Rightarrow \quad \boxed{I_B = 0{,}1\text{mA}}$$

$$I_C = \beta_F I_B \quad \Rightarrow \quad \boxed{I_C = 10\text{mA}}$$

$$I_E = I_B(\beta_F + 1) \quad \Rightarrow \quad \boxed{I_E = 10{,}1\text{mA}}$$

$$V_E = R_E I_E \quad \Rightarrow \quad \boxed{V_E = 6\text{V}}$$

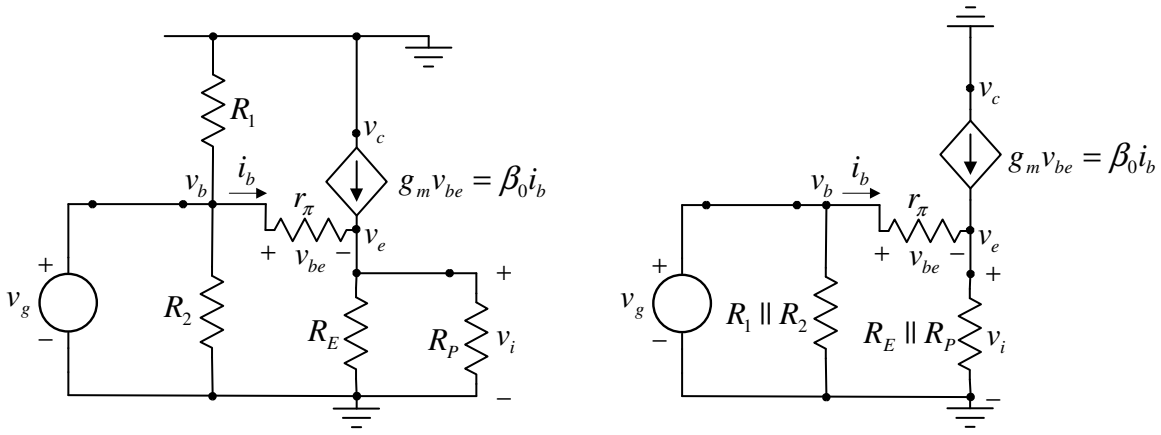
$$V_B = V_E + V_{BE} \quad \Rightarrow \quad \boxed{V_B = 6{,}7\text{V}}$$

$$V_C = V_{CC} \quad \Rightarrow \quad \boxed{V_C = 12\text{V}}$$

b) AC analiza:

Formiranje šeme za AC analizu:

- ukidanje svih jednosmernih generatora;
- zamena kondenzatora $C \to \infty$ kratkim spojevima;
- zamena tranzistora modelom za mali signal.



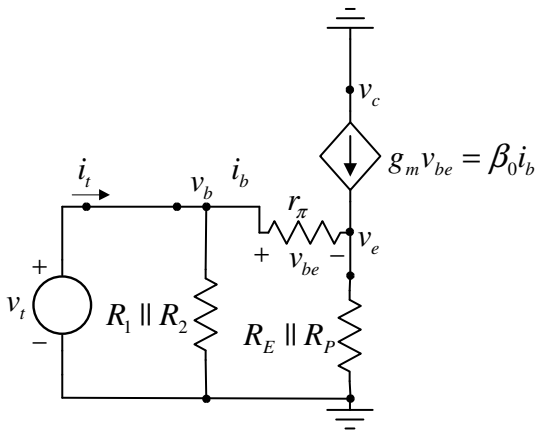
$$g_m = \frac{I_C}{V_t} = 384{,}6\text{mS}; \qquad r_\pi = \frac{\beta_0}{g_m} = 260\Omega;$$

$$i_b + \beta_0 i_b = \frac{v_i}{R_E \parallel R_P}; \quad i_b = \frac{v_{be}}{r_\pi} = \frac{v_g - v_i}{r_\pi};$$

$$\frac{v_g - v_i}{r_\pi} = \frac{v_i}{(\beta_0 + 1)(R_E \parallel R_P)}; \quad a_v = \frac{v_i}{v_g} = \frac{\frac{\beta_0 + 1}{r_\pi}(R_E \parallel R_P)}{1 + \frac{\beta_0 + 1}{r_\pi}(R_E \parallel R_P)} \quad \Rightarrow \quad \boxed{a_v \approx 0{,}993}$$

Šema za računanje ulazne otpornosti:

- povezivanje naponskog test generatora v_t između ulazne tačke i mase i označavanje struje i_t;
- ukidanje svih nezavisnih generatora u ostatku kola;
- $R_{ul} = \frac{v_t}{i_t}$;



$$i_t = \frac{v_t}{R_1 \parallel R_2} + i_b ;$$

$$i_b + \beta_0 i_b = \frac{v_e}{R_E \parallel R_P} \quad \Rightarrow \quad i_b = \frac{v_e}{(\beta_0 + 1)(R_E \parallel R_P)} ;$$

$$i_b = \frac{v_e}{(\beta_0 + 1)(R_E \parallel R_P)} = \frac{v_t - v_e}{r_\pi} ;$$

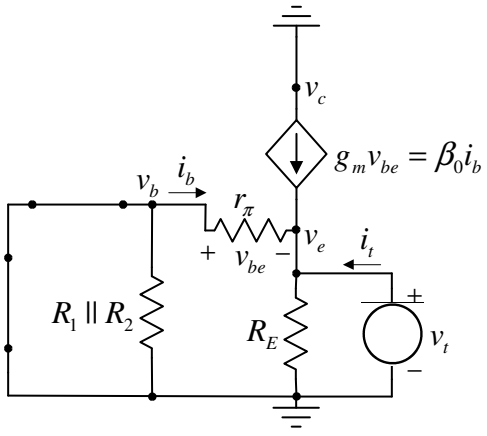
$$v_e = \frac{(\beta_0 + 1)(R_E \parallel R_P)}{r_\pi + (\beta_0 + 1)(R_E \parallel R_P)} \cdot v_t ;$$

$$i_t = \frac{v_t}{R_1 \parallel R_2} + \frac{v_t}{r_\pi + (\beta_0 + 1)(R_E \parallel R_P)} ;$$

$$R_{ul} = \frac{v_t}{i_t} = \left[\frac{1}{R_1 \parallel R_2} + \frac{1}{r_\pi + (\beta_0 + 1)(R_E \parallel R_P)} \right]^{-1} \quad \Rightarrow \quad \boxed{R_{ul} = 9{,}68\,\text{k}\Omega}$$

Šema za računanje izlazne otpornosti:

- povezivanje naponskog test generatora v_t između izlazne tačke i mase i označavanje struje i_t;
- ukidanje svih nezavisnih generatora u ostatku kola;
- $R_{izl} = \frac{v_t}{i_t}$;



$$i_t + i_b + \beta_0 i_b = \frac{v_t}{R_E} ;$$

$$i_b = \frac{0 - v_t}{r_\pi} ;$$

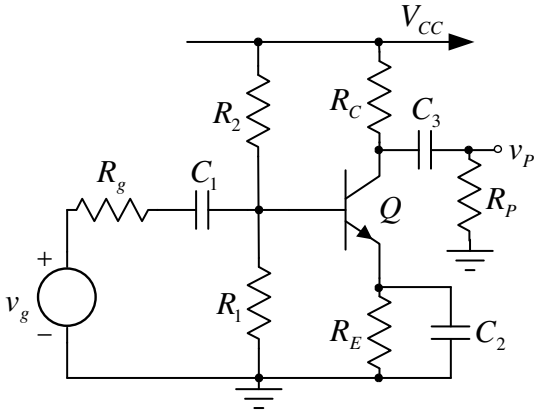
$$i_t = \frac{v_t}{R_E} + (1 + \beta_0)\frac{v_t}{r_\pi} ;$$

$$R_{izl} = \frac{v_t}{i_t} = \left[\frac{1}{R_E} + \frac{1 + \beta_0}{r_\pi} \right]^{-1} \quad \Rightarrow \quad \boxed{R_{izl} \approx 2{,}56\,\Omega}$$

83. Za pojačavač sa slike je poznato: $\beta_F = \beta_0 = 100$, $V_{BE} = 0{,}7\text{V}$, $V_t = 26\text{mV}$, $V_{CC} = 12\text{V}$, $C_1 \to \infty$, $C_2 \to \infty$, $C_3 \to \infty$, $R_g = 1\text{k}\Omega$, $R_1 = 10\,\text{k}\Omega$, $R_2 = 30\,\text{k}\Omega$, $R_C = 4{,}3\text{k}\Omega$, $R_E = 1{,}3\text{k}\Omega$ i $R_P = 100\,\text{k}\Omega$.

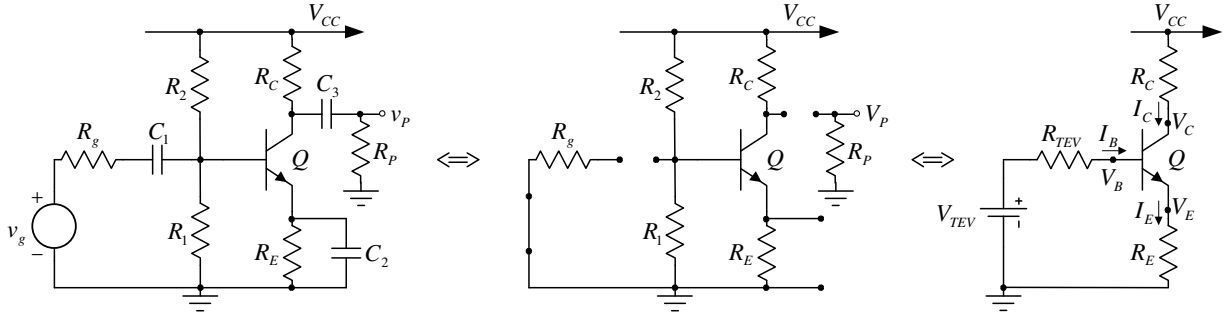
a) Izračunati jednosmerne struje (I_B, I_C i I_E) i jednosmerne napone tranzistora (V_B, V_C i V_E).

b) Izračunati naponsko pojačanje pojačavača $a_v = \dfrac{v_p}{v_g}$, ulaznu otpornost koju vidi generator naizmeničnog signala v_g i izlaznu otpornost koju vidi potrošač R_P.



Rešenje:

a) DC analiza:



$$V_{TEV} = \frac{R_1}{R_1 + R_2} V_{CC} = 3\text{V}; \qquad R_{TEV} = R_1 \parallel R_2 = \frac{R_1 R_2}{R_1 + R_2} = 7{,}5\text{k}\Omega;$$

Tranzistor je u DAR-u (preduslov da bi pojačavač ispravno radio).

$$R_E I_E + V_{BE} + R_{TEV} I_B - V_{TEV} = 0; \qquad I_E = I_B(\beta_F + 1);$$

$$I_B = \frac{V_{TEV} - V_{BE}}{R_{TEV} + (\beta_F + 1)R_E} \quad \Rightarrow \quad \boxed{I_B = 16{,}57\mu\text{A}}$$

$$I_C = \beta_F I_B \quad \Rightarrow \quad \boxed{I_C = 1{,}657\text{mA}}$$

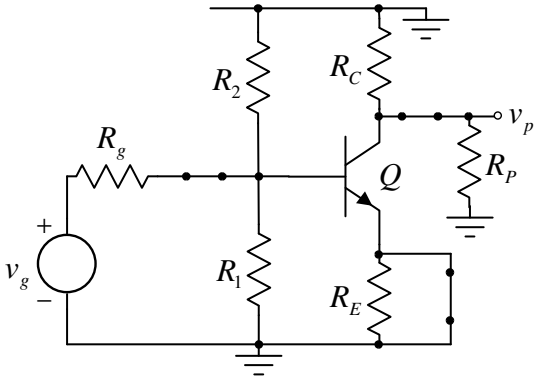
$$I_E = I_B(\beta_F + 1) \quad \Rightarrow \quad \boxed{I_E = 1{,}674\text{mA}}$$

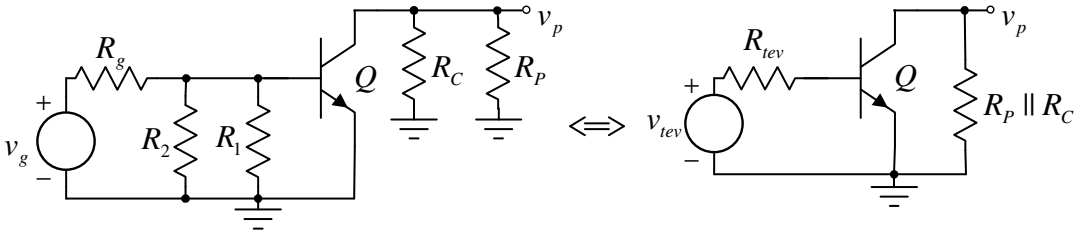
$$V_E = R_E I_E \quad \Rightarrow \quad \boxed{V_E = 2{,}176\text{V}}$$

$$V_B = V_E + V_{BE} \quad \Rightarrow \quad \boxed{V_B = 2{,}876\text{V}}$$

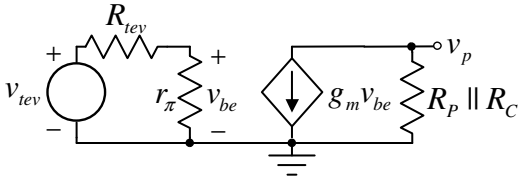
$$V_C = V_{CC} - R_C I_C \quad \Rightarrow \quad \boxed{V_C = 4{,}875\text{V}}$$

b) AC analiza:





$$R_{tev} = R_1 \parallel R_2 \parallel R_g = 882\Omega \qquad v_{tev} = \frac{R_1 \parallel R_2}{R_g + R_1 \parallel R_2} v_g = 0{,}88 v_g$$



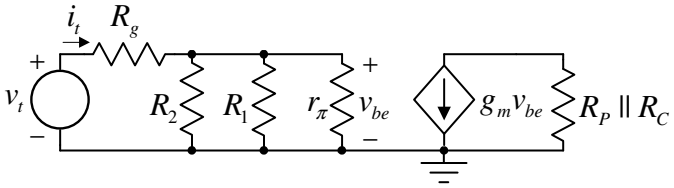
$$g_m = \frac{I_C}{V_t} = 63{,}73\text{mS} \qquad r_\pi = \frac{\beta_0}{g_m} = 1{,}569\text{k}\Omega$$

$$v_p = -g_m v_{be}\left(R_P \parallel R_C\right) \qquad v_{be} = \frac{r_\pi}{r_\pi + R_{tev}} \cdot v_{tev} = \frac{r_\pi}{r_\pi + R_{tev}} \cdot 0{,}88 v_g$$

$$v_p = -g_m\left(R_P \parallel R_C\right) \cdot \frac{r_\pi}{r_\pi + R_{tev}} \cdot 0{,}88 v_g$$

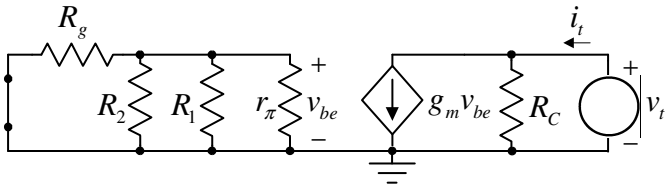
$$a_v = \frac{v_p}{v_g} = -0{,}88\, g_m\left(R_P \parallel R_C\right) \cdot \frac{r_\pi}{r_\pi + R_{tev}} \quad \Rightarrow \quad \boxed{a_v = -148}$$

Računanje ulazne otpornosti:



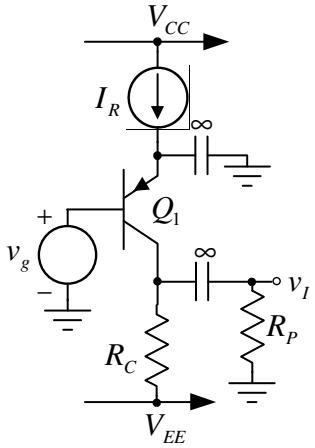
$$R_{ul} = \frac{v_t}{i_t} = R_g + R_1 \parallel R_2 \parallel r_\pi \quad \Rightarrow \quad \boxed{R_{ul} = 2{,}3\text{k}\Omega}$$

Računanje otpornosti koju vidi potrošač:



$$v_{be} = 0 \quad \Rightarrow \quad g_m v_{be} = 0 \quad \Rightarrow \quad v_t = R_C i_t \quad \Rightarrow \quad R_{izl} = \frac{v_t}{i_t} = R_C \quad \Rightarrow \quad \boxed{R_{izl} = 4{,}3\text{k}\Omega}$$

84. Parametri tranzistora u pojačavaču sa slike su: $\beta_F = \beta_0 = 50$ i $V_{EB} = 0{,}6\,\text{V}$, dok je: $V_{CC} = -V_{EE} = 5\text{V}$, $I_R = 1\text{mA}$, $V_t = kT/q = 25\text{mV}$, $R_C = 3\,\text{k}\Omega$ i $R_P = 30\,\text{k}\Omega$.



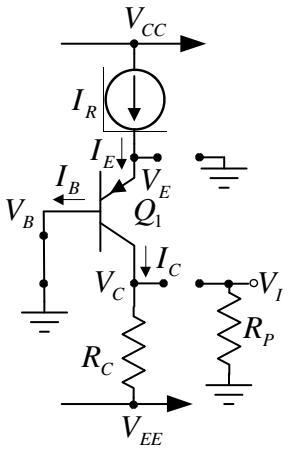
a) Odrediti jednosmerne struje baze, kolektora i emitora, kao i jednosmerne napone na bazi, kolektoru i emitoru.

b) Odrediti naponsko pojačanje pojačavača $a = v_i / v_g$.

c) Odrediti ulaznu otpornost pojačavača i otpornost koju vidi potrošač.

Rešenje:

a) DC analiza:



$$I_E = I_R \quad \Rightarrow \quad \boxed{I_E = 1\text{mA}}$$

$$I_B = \frac{I_E}{\beta_F + 1} \quad \Rightarrow \quad \boxed{I_B = 19{,}61\mu\text{A}}$$

$$I_C = \beta_F I_B \quad \Rightarrow \quad \boxed{I_C = 0{,}98\text{mA}}$$

$$\boxed{V_B = 0}$$

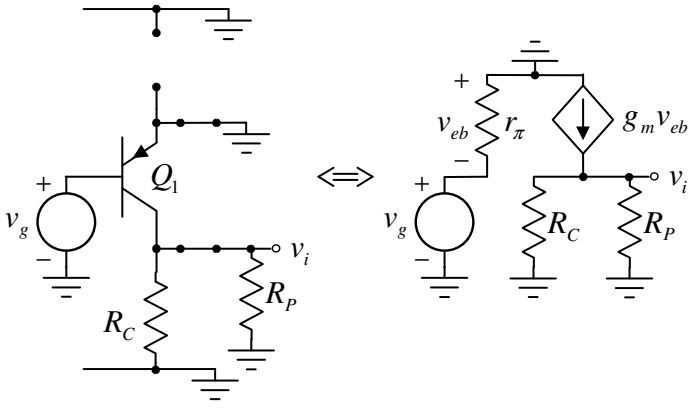
$$V_E = V_B + V_{EB} \quad \Rightarrow \quad \boxed{V_E = 0{,}6\text{V}}$$

$$V_C = V_{EE} + R_C I_C \quad \Rightarrow \quad \boxed{V_C = -2{,}06\text{V}}$$

b) AC analiza:

$$g_m = \frac{I_C}{V_t} = 39{,}2\text{mS}$$

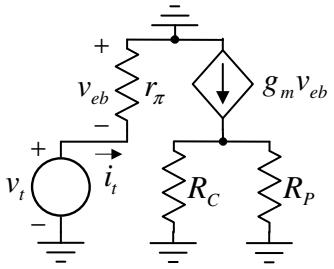
$$r_\pi = \frac{\beta_0}{g_m} = 1{,}275\text{k}\Omega$$



$v_{eb} = -v_g$

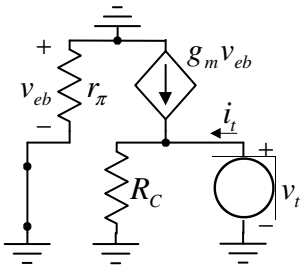
$$v_i = g_m v_{eb}\left(R_C \parallel R_P\right) = -g_m v_g \left(R_C \parallel R_P\right) \quad \Rightarrow \quad a = \frac{v_i}{v_g} = -g_m \left(R_C \parallel R_P\right) \quad \Rightarrow \quad \boxed{a = -106{,}9}$$

c) Računanje ulazne otpornosti:



$$v_t = r_\pi i_t \quad \Rightarrow \quad R_{ul} = \frac{v_t}{i_t} = r_\pi \quad \Rightarrow \quad \boxed{R_{ul} = 1{,}275\text{k}\Omega}$$

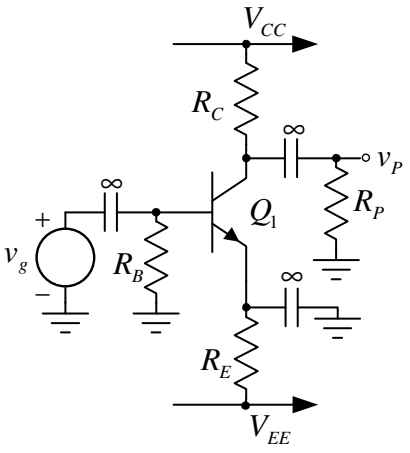
Računanje otpornosti koju vidi potrošač:



$$v_{eb} = 0 \quad \Rightarrow \quad g_m v_{eb} = 0 \quad \Rightarrow \quad v_t = R_C i_t \quad \Rightarrow \quad R_{izl} = \frac{v_t}{i_t} = R_C$$

$$\boxed{R_{izl} = 3\text{k}\Omega}$$

85. (Zadatak za vežbu) Parametri tranzistora u pojačavaču sa slike su: $\beta_F = \beta_0 = 100$ i $V_{BE} = 0{,}6\,\text{V}$, dok je: $V_{CC} = -V_{EE} = 5\text{V}$, $V_t = kT/q = 25\text{mV}$, $R_C = 4{,}7\text{k}\Omega$, $R_E = 4{,}7\text{k}\Omega$, $R_B = 47\text{k}\Omega$ i $R_P = 10\text{k}\Omega$.



a) Odrediti jednosmerne struje baze, kolektora i emitora, kao i jednosmerne napone na bazi, kolektoru i emitoru.

b) Odrediti naponsko pojačanje pojačavača $a = v_p / v_g$.

c) Odrediti ulaznu otpornost pojačavača i otpornost koju vidi potrošač.

Rešenje:

a) $\boxed{I_B \approx 8{,}43\,\mu\text{A}}$ $\boxed{I_C \approx 843\,\mu\text{A}}$ $\boxed{I_E \approx 851{,}4\,\mu\text{A}}$

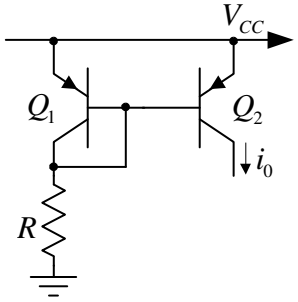
$\boxed{V_B = -0{,}396\text{V}}$ $\boxed{V_E = -0{,}996\text{V}}$ $\boxed{V_C = 1{,}038\text{V}}$.

b) $\boxed{a = -107{,}8}$

c) $R_{ul} = R_B \parallel r_\pi \quad \Rightarrow \quad \boxed{R_{ul} = 2{,}79\text{k}\Omega}$

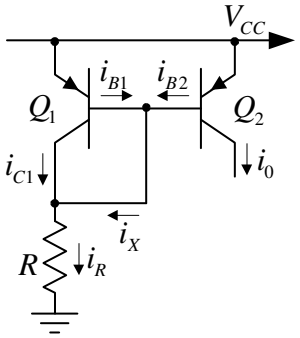
$R_{izl} = R_C \quad \Rightarrow \quad \boxed{R_{izl} = 4{,}7\text{k}\Omega}$

86. U strujnom izvoru sa slike oba tranzistora su identičnih karakteristika, pri čemu je $V_{EB} = 0{,}6\text{V}$ i $\beta_F = 50$. Poznato je i $V_{CC} = 10\text{V}$ i $R = 10\text{k}\Omega$. Izračunati struju i_0 koju generiše strujni izvor.



Rešenje:

$$\left.\begin{aligned} i_{C1} &= I_S \cdot e^{\frac{v_{EB1}}{V_t}} \\ i_{C2} &= I_S \cdot e^{\frac{v_{EB2}}{V_t}} \\ v_{EB1} &= v_{EB2} \end{aligned}\right\} \quad \Rightarrow \quad i_{C1} = i_{C2} = i_0 \quad \Rightarrow \quad i_{B1} = i_{B2}$$

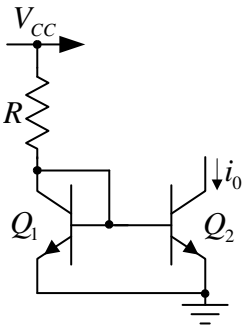


$i_X = i_{B1} + i_{B2} = 2i_{B1}$

$$i_R = i_{C1} + i_X = i_{C1} + 2i_{B1} = i_{C1} + 2\frac{i_{C1}}{\beta_F} = i_{C1}\left(1 + \frac{2}{\beta_F}\right) \quad \Rightarrow \quad i_{C1} = i_0 = \frac{i_R}{1 + \frac{2}{\beta_F}}$$

$i_R = \dfrac{V_{CC} - V_{EB}}{R} = 0{,}94\text{mA} \quad \Rightarrow \quad \boxed{i_0 = 903{,}85\mu\text{A}}$

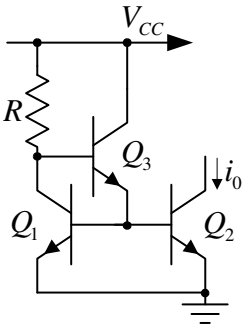
87. (Zadatak za vežbu) U strujnom izvoru sa slike oba tranzistora su identičnih karakteristika, pri čemu je $V_{BE} = 0{,}6\text{V}$ i $\beta_F = 100$. Poznato je i $V_{CC} = 5\text{V}$ i $R = 1\text{k}\Omega$. Izračunati struju i_0 koju generiše strujni izvor.



Rešenje:

$$\boxed{i_0 = 4{,}314\text{mA}}$$

88. (Zadatak za vežbu) U strujnom izvoru sa slike svi tranzistori su identičnih karakteristika. Smatrajući da su V_{BE}, β_F, V_{CC} i R poznate veličine, izračunati struju i_0 koju generiše strujni izvor.



Rešenje:

$$\boxed{i_0 = \frac{V_{CC} - 2V_{BE}}{R \cdot \left(1 + \dfrac{2}{\beta_F(\beta_F + 1)}\right)}}$$