Ηλεκτρονική Ι

Χρήστος Τσιώλης
03117176

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2η Σειρά Ασκήσεων

Άσκηση 1 (6.3)

$$i_{C_1} = I_{S_1} \cdot \exp\left(\frac{V_{BE}}{V_T}\right) \Rightarrow I_{S_1} \cdot e^{30} = 200 \cdot 10^{-6} \Rightarrow I_{S_1} = 1{,}87 \cdot 10^{-17}\ A$$

$$\frac{I_{S_2}}{I_{S_1}} = \frac{32 A_E q D_n \cdot n_{P_0}/W}{A_E q D_n n_{P_0}/W} = 32 \Rightarrow I_{S_2} = 32 I_{S_1} = 59{,}84 \cdot 10^{-17}\ A$$

$$i_{C_2} = I_{S_2} \cdot \exp\left(\frac{V_{BE}}{V_T}\right) = I_{S_2} \cdot e^{30} = 6{,}4\ mA$$

$$V_{BE} = V_T \cdot \ln\left(\frac{i_{C_2}}{I_{S_2}}\right) \Rightarrow V_{BE} = 28{,}14\ V_T$$

Άσκηση 2 (6.4)

$$\frac{i_{C_1}}{i_{C_2}} = 1 = \frac{I_{S_1} \cdot \exp\left(\frac{V_{BE_1}}{V_T}\right)}{I_{S_2} \cdot \exp\left(\frac{V_{BE_2}}{V_T}\right)} = 25 \cdot 10^4 \exp\left(V_{BE_1} - V_{BE_2}\right)$$

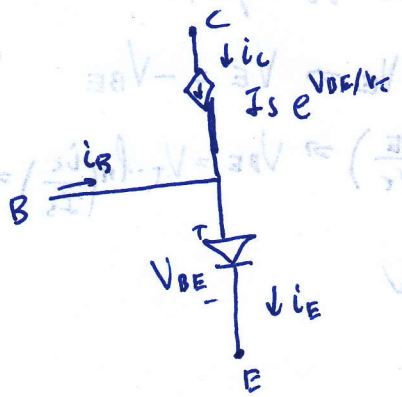
- $A_{E_1} = 25 \cdot 10^4\ A_{E_2}$

$$\Rightarrow V_{BE_1} - V_{BE_2} = 12{,}43\ V$$

Άσκηση 3 (6.16)

$i_C = 1\ mA$, $V_{BE} = 0{,}7\ V$, $i_B = 10\ \mu A$, $i_E = 1{,}01\ mA$

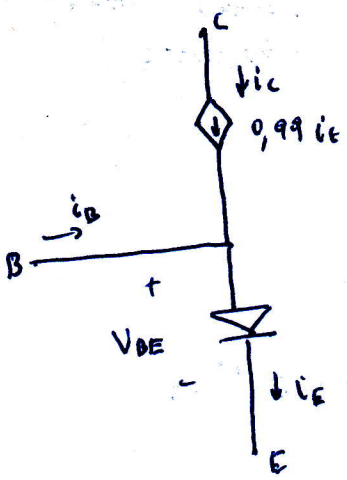
a)



$V_T = 25_m\ V$

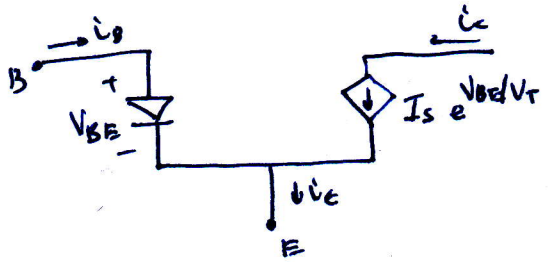
$I_S = 10^{-15}$

β)



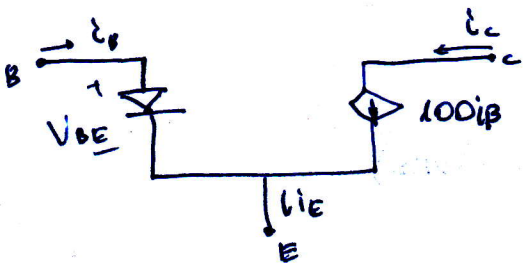
$$\frac{i_C}{i_E} = \alpha = \frac{1\,mA}{1{,}01\,mA} = 0{,}99$$

γ)

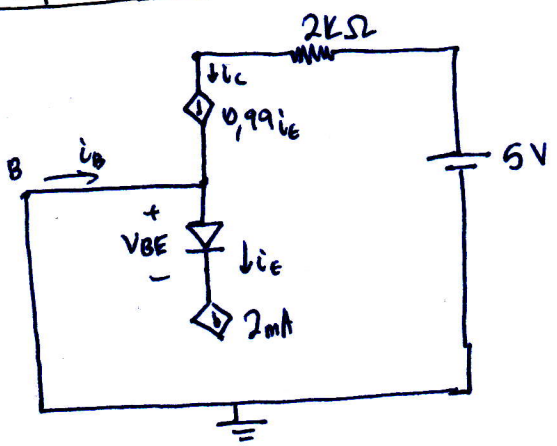


$$\frac{\beta}{\beta+1} = 0{,}99 \Rightarrow \beta = 100$$

δ)



Άσκηση 4 (6.17)



$i_E = 2\,mA$

$i_C = 0{,}99 \cdot 2\,mA = 1{,}98\,mA$

$i_C + i_B = i_E \Rightarrow i_B = 0{,}02\,mA$

$5 - V_C = 2000\, i_C \Rightarrow V_C = 1{,}04\,V$

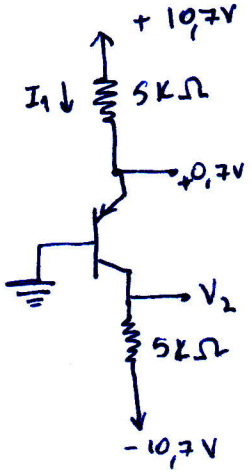
$V_{BE} = V_B - V_E = -V_E \Rightarrow V_E = -V_{BE}$

$i_C = I_S \cdot \exp\left(\frac{V_{BE}}{V_T}\right) \Rightarrow V_{BE} = V_T \cdot \ln\left(\frac{i_C}{I_S}\right) = 0{,}67$

Άρα $V_E = -0{,}67\,V$

Άσκηση 5 (6.28)

α)



$B = \frac{i_C}{i_B}$

$i_B + i_C = i_C$

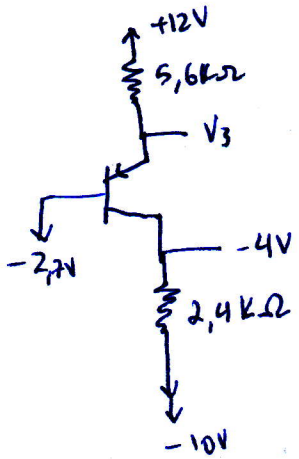
$i_C = i_B + i_C \xrightarrow{\gg\beta} i_E \simeq i_C$

$I_1 = \frac{10,7V - 0,7V}{5K\Omega} = \frac{10V}{5\cdot10^3\Omega} = 2mA$

$I_C = \frac{V_2 - (-10,7V)}{5K\Omega} \Rightarrow 2\cdot10^{-3} = \frac{V_2 + 10,7V}{5\cdot10^3\Omega} \Rightarrow$

$\Rightarrow 10 = V_2 + 10,7 \Rightarrow V_2 = -0,7V$

β)

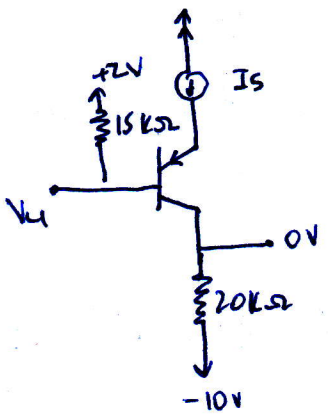


$I_C = \frac{(-4) - (-10V)}{2,4K\Omega} = \frac{10V - 4V}{2,4\cdot10^3\Omega} = 2,5mA$

$I_E = \frac{12 - (+V_3)}{5,6K\Omega} \Rightarrow 2,5\cdot10^{-3} = \frac{(12 - V_3)V}{5,6\cdot10^3\Omega} \Rightarrow$

$\Rightarrow 12 - V_3 = 14 \Rightarrow V_3 = -2V$

γ)



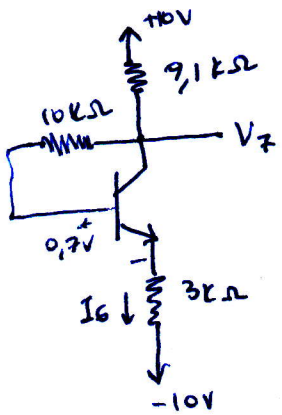
$I_C = \frac{0 - (-10)}{20K\Omega} = \frac{10V}{20\cdot10^3\Omega} = 0,5mA$

για $\gg\beta$: $i_C \simeq i_C$ άρα $I_S = 0,5mA$

για $\gg\beta$: $I_B = 0$

$I_B = \frac{V_4 - 2}{15K\Omega} \Rightarrow 0 = \frac{V_4 - 2}{15K\Omega} \Rightarrow V_4 = 2V$

δ)



$I_C \simeq I_E = I_6$

$I_B \simeq \frac{I_C}{\beta} \simeq 0A$

ΝΤΚ: $-10 + (9,1\cdot10^3)\cdot I_C + (10\cdot10^3) I_B + 0,7 + (3\cdot10^3) I_6 - 10 = 0$

$\rightarrow (9,1\cdot10^3) I_C + (10\cdot10^3) I_B + (3\cdot10^3) I_6 = 19,3$

$\Rightarrow (9,1\cdot10^3) I_6 + (10\cdot10^3)\cdot 0 + (3\cdot10^3) I_6 = 19,3$

$\Rightarrow (12,1\cdot10^3) I_6 = 19,3 \Rightarrow I_6 = \frac{19,3}{12,1\cdot10^3} \Rightarrow$

$\Rightarrow I_6 = 1,595mA$

$I_C = 10 - V_7 \Rightarrow V_7 = 10 - (9,1\cdot10^3) I_C \Rightarrow$

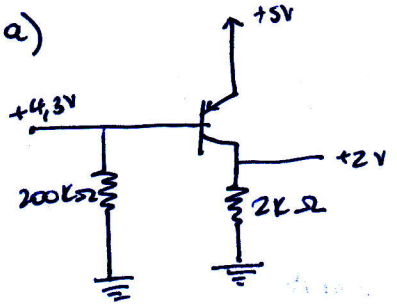
$\Rightarrow V_7 = 10 - (9,1\cdot10^3)\cdot I_6 \Rightarrow$

$\Rightarrow V_7 = 10 - (9,1\cdot10^3)(1,595\cdot10^{-3}) \Rightarrow$

$\Rightarrow V_7 = -4,5145V$

Άσκηση 6 (6.29)

α)



$V_{BE} = 4,3 - 5V = -0,7V$

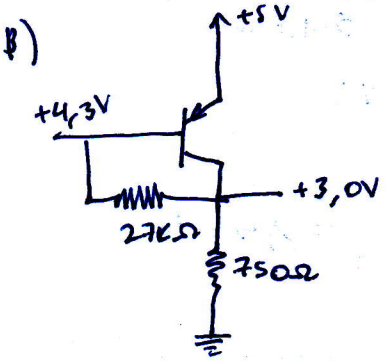
$V_c = 2V$

$i_B = \frac{4,3}{200k} = 21,5\,\mu A$

$i_C = \frac{2}{2000} = 1mA$

$\beta = \frac{i_C}{i_B} = 47$

β)



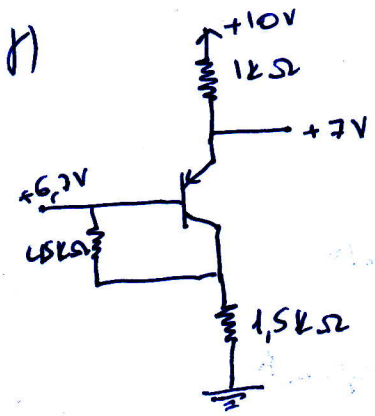
$i_B = \frac{4,3-3}{27k} = 0,048\,mA$

$I_{750\Omega} = 4mA = \frac{3-0}{750}$

$i_B + i_C = 4mA \Rightarrow i_C = 3,95mA$

$\Rightarrow \beta = \frac{i_C}{i_B} = 82$

γ)



$I_E = \frac{10-7}{1000} = \frac{3}{1000} = 3mA$

$V_C = I_{1k\Omega}(1,5\cdot10^3) = (I_C + I_B)\cdot(1,5\cdot10^3) =$

$= I_E(1,5\cdot10^3) = 3\cdot10^{-3}\cdot1,5\cdot10^3 = 4,5V$

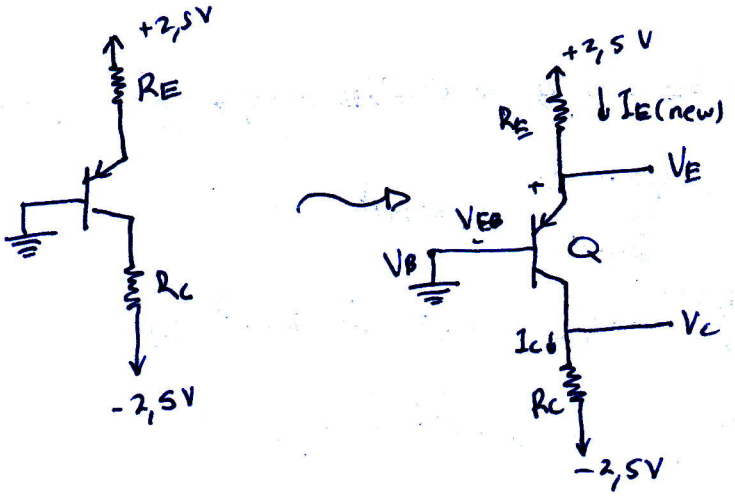
$I_B = \frac{6,3-V_C}{4,5\cdot10^3} = \frac{6,3-4,5}{4,5\cdot10^3} = 0,04\cdot10^{-3} = 0,04\,mA$

$I_B + I_C = I_{1k\Omega}$

$I_C = I_E - I_B = 3\cdot10^{-3} - 0,04\cdot10^{-3} = 2,96\cdot10^{-3} = 2,96mA$

$\beta = \frac{I_C}{I_B} = \frac{2,96\cdot10^{-3}}{0,04\cdot10^{-3}} = 74$

Άσκηση 4 (6.32)



- $V_{EB} = V_{EB} + N_T \cdot \ln\left(\frac{I_{E(new)}}{I_E}\right) \Rightarrow V_{EB} = 0,64 + 25\cdot10^{-3} \cdot \ln\left(\frac{0,5\cdot10^{-3}}{0,1\cdot10^{-3}}\right) \rightarrow$

$\Rightarrow V_{EB} = 0,64 + 0,04 \Rightarrow V_{EB} = 0,68\,V$

- $-2,5 + I_{E(new)} \cdot R_E + V_{EB} = 0 \Rightarrow -3,5 + 0,5\cdot10^{-3}\cdot R_E + 0,68 = 0 \Rightarrow$

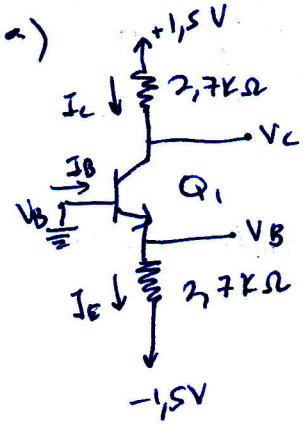
$\Rightarrow R_E = \frac{2,5 - 0,68}{0,5\cdot10^{-3}} = 3,6\,k\Omega$

- $I_C = \left(\frac{\beta}{\beta+1}\right)\cdot I_{E(new)} \simeq \frac{100}{100+1}\cdot 0,5\cdot10^{-3} = 0,49\,mA$

- $R_C = \frac{V_C - (-3,5)}{I_C} = -\frac{0,5+2,5}{0,49\cdot10^{-3}} = \frac{2}{0,49\cdot10^{-3}} \simeq 4,08\,k\Omega$

Άσκηση 8 (6.35)

a)



$V_B = 0V$

$|V_{BE}| = 0,8 \Rightarrow V_B - V_E = 0,8 \Rightarrow 0 - V_E = 0,8 \Rightarrow V_E = -0,8V$

$I_E = \frac{V_E - (-1,5)}{2,7\cdot10^3} = -\frac{0,8+1,5}{2,7\cdot10^3} = \frac{0,7}{2,7\cdot10^3} = 259,2\,\mu A$

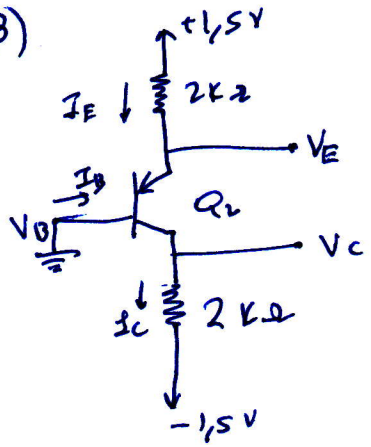
$I_C = \left(\frac{\beta}{\beta+1}\right)\cdot I_E = \frac{50}{50+1}\cdot 259,2\cdot10^{-6} = 254,11\,\mu A$

$I_C = \frac{1,5 - V_C}{2,7\cdot10^3} \Rightarrow V_C = 1,5 - I_C\cdot 2,7\cdot10^3 \Rightarrow$

$\Rightarrow V_C = 1,5 - 254,11\cdot10^{-6}\cdot 2,7\cdot10^3 \simeq 0,813V$

$I_\beta = \frac{I_C}{\beta} = \frac{254,11\cdot10^{-6}}{50} = 5,08\,\mu A$

β)



$V_B = 0\,V$

$|V_{BE}| = 0{,}8 \Rightarrow V_B - V_E = -0{,}8 \Rightarrow 0 - V_E = -0{,}8 \Rightarrow V_E = 0{,}8V$

$I_E = \frac{1{,}5 - V_E}{2\cdot 10^3} = \frac{1{,}5 - 0{,}8}{2\cdot 10^3} = 0{,}35\,mA$

$I_C = \frac{V_C - (-1{,}5)}{2\cdot 10^3} \Rightarrow V_C = -1{,}5 - I_C \cdot 2\cdot 10^3$ (1)

$I_C = \frac{\beta}{\beta+1}\cdot I_E = \frac{50}{50+1}\cdot 0{,}35\cdot 10^{-3} = 343{,}13\,\mu A$

(1) $\Rightarrow V_C = -1{,}5 + 343{,}13\cdot 10^{-4}\cdot 2\cdot 10^3 = -1{,}15V$

$I_B = \frac{I_C}{\beta} = \frac{345{,}13\cdot 10^{-6}}{50} = 6{,}86\cdot 10^{-4} = 6{,}86\,\mu A$

Άσκηση 9 (6.39)

α) Η τάση V_{EB} μειώνεται $2mV/°C$ για κάθε αύξηση $1°C$.

$V_{EB}(50°C) = V_{EB}(20°C) - (2\cdot 10^{-3})(50°-20°) \Rightarrow$

$\Rightarrow V_{EB}(50°C) = (692\cdot 10^{-3}) - (2\cdot 10^{-3})\cdot(30) = (692\cdot 10^{-3}) - (60\cdot 10^{-3}) = 0{,}632V$

β). $i_E = \frac{I_S}{a}\exp\left(\frac{V_{EB}}{V_T}\right) = \frac{I_S}{a}\exp\left(\frac{700\cdot 10^{-3}}{25\cdot 10^{-3}}\right)$ (1)

• $i_E(20°C) = \frac{I_S}{a}\exp\left(\frac{V_{EB}}{V_T}\right) \Rightarrow (0{,}5\cdot 10^{-3}) = \frac{I_S}{a}\exp\left(\frac{692\cdot 10^{-3}}{25\cdot 10^{-3}}\right)$ (2)

$\frac{(1)}{(2)} \Rightarrow \frac{i_E}{0{,}5\cdot 10^{-3}} = \frac{\frac{I_S}{a}\exp\left(\frac{700\cdot 10^{-3}}{25\cdot 10^{-3}}\right)}{\frac{I_S}{a}\exp\left(\frac{692\cdot 10^{-3}}{25\cdot 10^{-3}}\right)} \Rightarrow i_E = (0{,}5\cdot 10^{-3})\frac{\exp\left(\frac{700\cdot 10^{-3}}{25\cdot 10^{-3}}\right)}{\exp\left(\frac{692\cdot 10^{-3}}{25\cdot 10^{-3}}\right)} \Rightarrow$

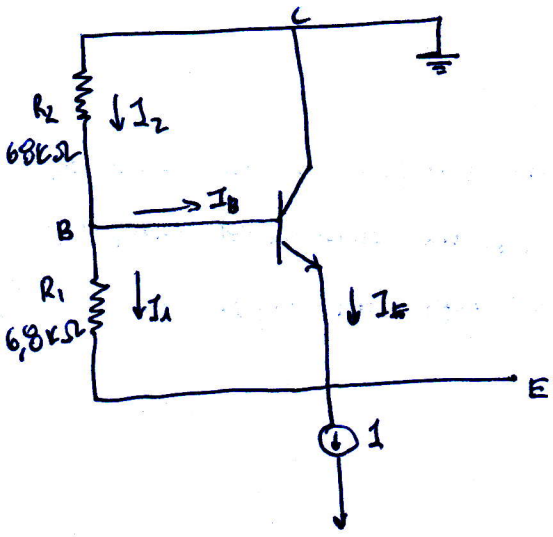
$\Rightarrow i_E = (0{,}5\cdot 10^{-3})\cdot\exp\left(\frac{700}{25} - \frac{692}{25}\right) = 6{,}89\cdot 10^{-4} = 0{,}689\,mA$ για $20°C$

• $i_E(50°C) = \frac{I_S}{a}\exp\left(\frac{V_{EB}}{V_T}\right) \Rightarrow 0{,}5\cdot 10^{-3} = \frac{I_S}{a}\exp\left(\frac{632\cdot 10^{-3}}{25\cdot 10^{-3}}\right)$ (3)

$\frac{(1)}{(3)} \Rightarrow \frac{i_E}{0{,}5\cdot 10^{-3}} = \frac{\frac{I_S}{a}\exp\left(\frac{700\cdot 10^{-3}}{25\cdot 10^{-3}}\right)}{\frac{I_S}{a}\exp\left(\frac{632\cdot 10^{-3}}{25\cdot 10^{-3}}\right)} \Rightarrow i_E = (0{,}5\cdot 10^{-3})\frac{\exp\left(\frac{700\cdot 10^{-3}}{25\cdot 10^{-3}}\right)}{\exp\left(\frac{632\cdot 10^{-3}}{25\cdot 10^{-3}}\right)} \Rightarrow$

$\Rightarrow i_E = (0{,}5\cdot 10^{-3})\cdot\exp\left(\frac{700}{25} - \frac{632}{25}\right) = 7{,}59\cdot 10^{-3} = 7{,}59\,mA$ για $50°C$

Άσκηση 10 (6.42)



Στους 25°C $V_{BE} = 680mV$, $I_E = 1mA$

και $I = 1,1A$

ΝΡΚ στον Ε κοβ: $I_E + I_1 = I$

$I_1 = I - I_E = 1,1mA - 1mA = 0,1mA$

και $I_B = \frac{I_E}{\beta+1} = \frac{1mA}{100+1} \simeq 0,01mA$

ΝΡΚ στον Β κοβ: $I_2 = I_1 + I_B$

$= 0,1mA + 0,01mA$

$= 0,11mA$

Επομ, $V_E = -V_{R_2} - V_{R_1} = -I_2R_2 - I_1R_1 = -0,11mA \cdot (68K\Omega) - 0,1mA\,(6,8K\Omega)$

$= -7,48V - 0,68V = -8,16V$

$V_E = -(I_2R_2 + I_1R_1) = -[(I_1 + I_B)R_2 + I_1 \cdot R_1] =$

$= -\left[\left(\frac{V_{BE}}{R_1} + I_B\right) \cdot R_2 + \frac{V_{BE}}{R_1} \cdot R_1\right] = -\frac{V_{BE}}{R_1} \cdot R_2 + V_{BE} + I_B R_2 =$

$= -\left(\frac{R_2}{R_1} + 1\right) V_{BE} + I_B \cdot R_2$

$I_B \ll$, $V_E = -\left(\frac{R_2}{R_1} + 1\right) V_{BE}$ και για $V_{BE} = -2mV/°C$

$T_C(V_E) = -\left(\frac{R_2}{R_1} + 1\right)(-2mV/°C) = \left(\frac{68}{6,8} + 1\right)(2mV/°C) = 22mV/°C$

Επομ, $V_E(75°C) = V_E(25°C) + TC(50°C) = -8,16V + 22mV/C°\,(50°C) = -8,16 + 1,1V \Rightarrow$

$\Rightarrow V_E(75°C) = -7,06V$

Άσκηση 11 (6.52)

Για τύπο β : $I_C = \alpha I_E \rightsquigarrow I_C \simeq I_E$

$I_C = \frac{V_{CC} - V_C}{R_C}$, $I_E = \frac{V_E}{R_E}$

- Για να βρούμε την τιμή της τάσης της βάσης πρέπει να δούμε στην εξίσωση και στην αντίστοιχη τάσεις σχετικές με την τάση βάσης και να βγάλουμε τα ρεύματα αντίστοιχα εκπομπού.
- Για να λειτουργήσει το τρανζίστορ στο όριο του κορεσμού υπάρχει $V_{CE} = 0,3V$ και $V_{BE} = 0,7V$ αυτό:

$V_{BE} = V_B - V_E \Rightarrow V_E = V_B - V_{BE} = V_B - 0,7$

$V_{CE} = V_C - V_E \Rightarrow V_C = V_{CE} + V_E = 0,3 + V_B - 0,7 = V_B - 0,4$

$I_C \simeq I_E$

$\frac{V_{CC} - V_C}{R_C} = \frac{V_E}{R_E} \Rightarrow \frac{3 - (V_B - 0,4)}{1000} = \frac{V_B - 0,7}{1000} \Rightarrow \frac{3,4 - V_B}{1000} = \frac{V_B - 0,7}{1000} \Rightarrow$

$\Rightarrow 3,4 - V_B = V_B - 0,7 \Rightarrow 2V_B = 4,1 \Rightarrow V_B = 2,05V$

- Για να λειτουργήσει το τρανζίστορ στον κορεσμό υπάρχει $V_{CE} = 0,2V$, $V_{BE} = 0,7V$.

$V_{BE} = V_B - V_E \Rightarrow V_E = V_B - V_{BE} = V_B - 0,7$

$V_{CE} = V_C - V_E \Rightarrow V_C = V_{CE} + V_E = 0,2 + V_B - 0,7 = V_B - 0,5$

$I_C = \frac{V_{CC} - V_C}{R_C} = \frac{3 - (V_B - 0,5)}{1000}$

$I_E = \frac{V_E}{R_E} = \frac{V_B - 0,7}{1000}$

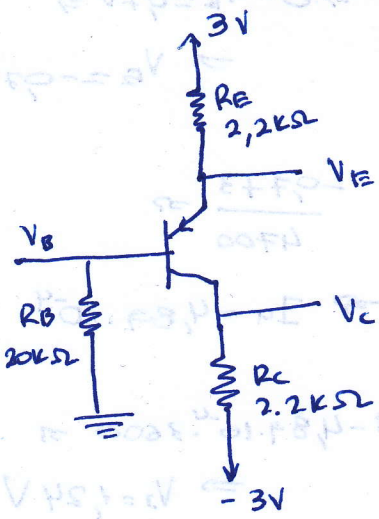
$I_B = I_E - I_C$

$I_B = \frac{V_B - 0,7}{1000} - \frac{3 - (V_B - 0,5)}{1000} = \frac{2 \cdot V_B - 4,2}{1000}$

$\beta_{forced} = \frac{I_C}{I_B} = \frac{\frac{3 - (V_B - 0,5)}{1000}}{\frac{2V_B - 4,2}{1000}} \Rightarrow 2 = \frac{3 - (V_B - 0,5)}{2V_B - 4,2} \Rightarrow 4V_B - 8,4 = 3,5 - V_B \Rightarrow$

$\Rightarrow V_B = 2,38V$

Άσκηση 12 (6.59)



$\beta = 50$

$V_{EB} = V_E - V_B$, $V_E = 3 - R_E \cdot I_E$

$V_B = R_B \cdot I_B$

$V_{EB} = 3 - R_E \cdot I_E - R_B \cdot I_B$

$V_{EB} = 3 - R_E \cdot I_E - R_B \cdot \frac{I_E}{\beta+1}$

$I_E = \frac{3 - V_{EB}}{R_E + R_B \cdot \frac{1}{\beta+1}} = \frac{3 - 0,7}{2200 + 20000 \cdot \frac{1}{50+1}} \Rightarrow$

$\Rightarrow I_E = 0,887 \cdot 10^{-3} A$

$I_B = \frac{I_E}{\beta+1} = \frac{0,887 \cdot 10^{-3}}{50+1} = 1,7 \cdot 10^{-5} A$

$I_C = I_E - I_B = 0,887 \cdot 10^{-3} - 1,7 \cdot 10^{-5} = 8,7 \cdot 10^{-4} A$

$V_B = R_B \cdot I_B = 1,7 \cdot 10^{-5} \cdot 2000 = 0,34 V$

$V_E = 3 - R_E \cdot I_E = 3 - 2200 \cdot 0,887 \cdot 10^{-3} = 1,05 V$

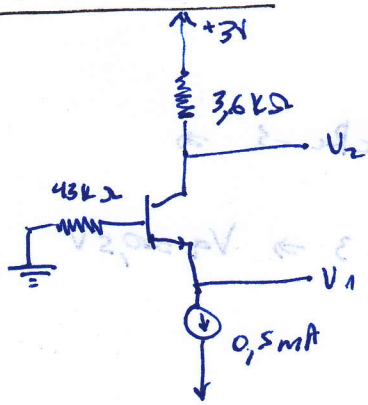
$V_C = R_C I_C - 3 = 2.200 \cdot 8,7 \cdot 10^{-4} - 3 = -1,09 V$

Το τρανζίστορ είναι ενεργό όταν: $V_C < V_B + 0,4 \Rightarrow V_C < 0,34 + 0,4 = 0,74$

Δηλ. $R_C = \frac{0,74 - (-3)}{8,7 \cdot 10^{-4}} = 4300 \Omega$

Άσκηση 13 (6.61)

a)



$V_{BE} = 0,7 V$

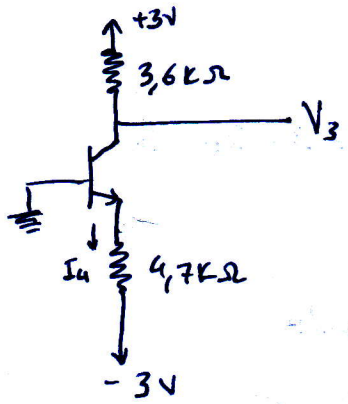
$V_B - V_E = 0,7 \Rightarrow 0 - V_E = 0,7 \Rightarrow V_E = V_1 = -0,7 V$

$I_C = \frac{3 - V_2}{3600}$

$V_2 = 3 - I_C \cdot R_C = 3 - 0,5 \cdot 10^{-3} \cdot 3600 \Rightarrow$

$\Rightarrow V_2 = 1,2 V$

β)



$V_{BE} = 0,7V \Rightarrow V_B - V_E = 0,7 \Rightarrow 0 - V_E = 0,7V \Rightarrow$

$\Rightarrow V_E = -0,7V$

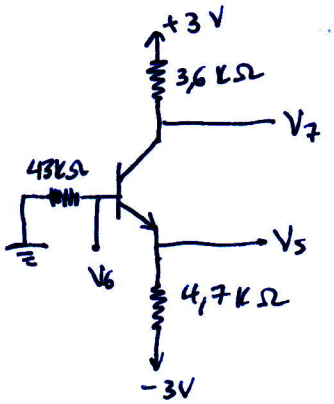
$I_4 = \frac{V_E - (-3)}{4700} \Rightarrow I_4 = \frac{-0,7+3}{4700} \Rightarrow$

$\Rightarrow I_4 = 4,89 \cdot 10^{-4}$

$I_C = \frac{3 - V_3}{3600} \Rightarrow V_3 = 3 - 4,89 \cdot 10^{-4} \cdot 3600 \Rightarrow$

$\Rightarrow V_3 = 1,24\,V$

γ)



$V_6 \approx 0V$

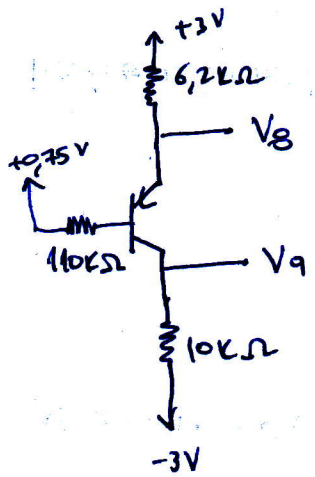
$V_{BE} = 0,7V \Rightarrow V_B - V_E = 0,7 \Rightarrow 0 - V_E = 0,7 \Rightarrow V_E = V_5 = -0,7V$

$I_E = \frac{V_5 - (-3)}{4700} = \frac{-0,7+3}{4700} = 4,89 \cdot 10^{-4}$

$I_C = \frac{3 - V_4}{3600}$ ~~kol~~ $V_7 = 3 - I_C R_C$

$V_7 = 3 - 4,89 \cdot 10^{-4} \cdot 3600 \Rightarrow V_7 = 1,2\,V$

δ)



$V_{EB} = 0,7V \Rightarrow V_E - V_B = 0,7V \Rightarrow V_E = 0,7 + V_B \Rightarrow$

$\Rightarrow V_E = 0,7 + 0,75 \Rightarrow V_E = V_8 = 1,45\,V$

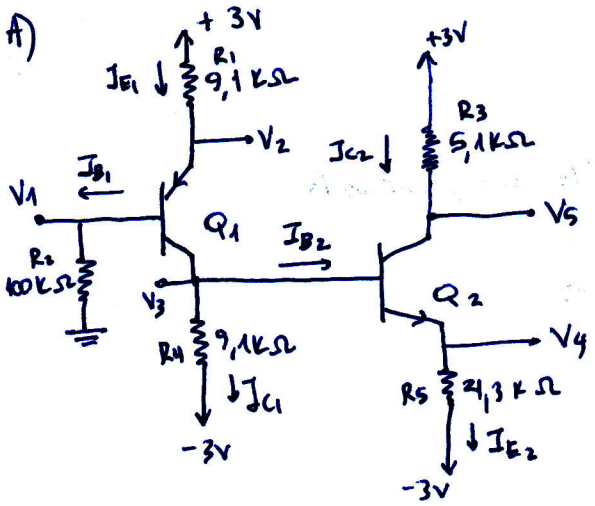
$I_B = \frac{3 - V_B}{6200} = \frac{3 - 1,45}{6200} = 2,5 \cdot 10^{-4}\,A$

$I_C = \frac{V_9 - (-3)}{R_C} \Rightarrow V_9 = I_C R_C - 3 \Rightarrow$

$\Rightarrow V_9 = 2,5 \cdot 10^{-4} \cdot 10.000 - 3 \Rightarrow V_9 = -0,5\,V$

Άσκηση 14 (6.66)

Α)



α) Για $\beta=\infty$:

Έχουμε $\beta=\frac{I_C}{I_B} \Rightarrow I_B=0$

$V_1 = I_{B_1} \cdot R_2 = 0V$

ΚΤΚ στο Q_1 : $-V_2 + V_{BE(Q_1)} + V_1 = 0 \Rightarrow -V_2 + 0,7V + 0V = 0 \Rightarrow V_2 = 0,7V$

ΚΤΚ στο Q_1 : $-V_3 + I_{C_1} \cdot R_4 - 3V = 0$ (1) $\quad (\beta=\infty,\ I_{C_1}=I_{E_1})$

* Στον εαυτό Q_1 : $-3V + I_{E_1} \cdot R_1 + V_2 = 0 \Rightarrow I_{E_1} = \frac{3V - V_2}{R_1} \Rightarrow$

$\Rightarrow I_{E_1} = \frac{3V - 0,7V}{9,1 \cdot 10^3 \Omega} = 0,2527 \cdot 10^{-3} A = 0,253\,mA$

(1) $\Rightarrow -V_3 + (0,253 \cdot 10^{-3} A) \cdot (9,1 \cdot 10^3 \Omega) - 3V = 0 \Rightarrow$

$\Rightarrow -V_3 + 2,3023V - 3V = 0 \Rightarrow -V_3 = 0,6977V \Rightarrow V_3 = -0,71V$

Στο Q_2 : $-V_3 + V_{BE(Q_2)} + V_4 = 0 \Rightarrow -(+0,7V) + 0,7V + V_4 = 0 \Rightarrow V_4 = -1,4V$

ΚΤΚ στο Q_2 : $-3V + R_3 I_{C_2} + V_S = 0$, $I_{C_2} = I_{E_2}$

$-V_4 + R_S \cdot I_{C_2} - 3V = 0 \Rightarrow -(-1,4V) + 4,3 \cdot 10^3 \cdot I_{E_2} = 3V \Rightarrow$

$\Rightarrow 4,3 \cdot 10^3 I_{E_2} = 3V - 1,4V \Rightarrow I_{E_2} = \frac{1,6V}{4,372 \cdot 10^3 A} = 0,372\,mA$

Άρα από I_{E_2} : $-3V + R_3 \cdot I_{C_2} + V_S = 0 \Rightarrow -3V + R_3 \cdot I_{E_2} + V_S = 0 \Rightarrow$

$\Rightarrow -3V + 5,1 \cdot 10^3 (0,372 \cdot 10^{-3}) = -V_S \Rightarrow$

$\Rightarrow -1,10V = -V_S \Rightarrow V_S = 1,1V$

β) Για $\beta = 100$:

$I_E = (\beta+1) I_B = 101\, I_B$

$I_{E1} = 101\, I_{B1} = 101 \cdot (2,257 \cdot 10^{-6})\,A = 2,2796 \cdot 10^{-4}\,A = 0,228\,mA$

ΝΤΚ Q_1 : $-3V + I_{E1} \cdot R_1 + V_{BE}(Q_1) + I_B \cdot R_2 = 0 \Rightarrow$

$\Rightarrow -3V + 101 \cdot I_{B1} \cdot R_1 + 0,7V + I_B \cdot R_2 = 0 \Rightarrow$

$\Rightarrow -2,3V + I_{B1}(101 R_1 + R_2) = 0 \Rightarrow$

$\Rightarrow (101 R_1 + R_2) \cdot I_{B1} = 2,3V \Rightarrow$

$\Rightarrow I_{B1} = \dfrac{2,3\,V}{1099,1 \cdot 10^3\,\Omega} = 0,002257 \cdot 10^{-3}\,A = 2,257 \cdot 10^{-6}\,A$

$V_1 = I_{B1} \cdot R_2 = (2,257 \cdot 10^{-6})(100 \cdot 10^3) = 0,2257\,V$

ΝΤΚ Q_1 : $-3V + I_{E1} \cdot R_1 + V_2 = 0 \Rightarrow V_2 = 3V - I_{E1} \cdot R_1 \Rightarrow$

$\Rightarrow V_2 = 3V - (0,228 \cdot 10^{-3}) \cdot (9,1 \cdot 10^3) = 0,9252V \Rightarrow V_2 = 0,925V$

ΝΤΚ Q_1 : $-V_3 + I_{C1} \cdot R_4 - 3V = 0 \Rightarrow I_{C1} \cdot R_4 - 3V = V_3 \Rightarrow \beta I_{B1} \cdot R_4 - 3V = V_3 \Rightarrow$

$\Rightarrow (9,1 \cdot 10^3)(100) \cdot (2,257 \cdot 10^{-6}) - 3V = V_3 \Rightarrow V_3 = -0,946V$

ΝΤΚ Q_2 : $-V_3 + V_{BE}(Q_2) + V_4 = 0 \Rightarrow V_4 = V_3 - V_{BE}(Q_2) \Rightarrow$

$\Rightarrow V_4 = -0,946V - 0,7V = -1,646V$

$-V_4 + R_5 \cdot I_{E2} - 3V = 0 \Rightarrow -(-1,646V) - 3V + R_5 I_{E2} = 0 \Rightarrow$

$\Rightarrow I_{E2} = \dfrac{1,354V}{4,3 \cdot 10^3\,\Omega} = 0,315 \cdot 10^{-7}\,A = 0,315\,mA$

ΝΤΚ Q_2 : $-3V + I_{C2} \cdot R_3 + V_5 = 0 \Rightarrow$

$\Rightarrow V_5 = 3V - I_{C2} R_3 \Rightarrow V_5 = 3V - I_{E2}\left(\dfrac{\beta}{\beta+1}\right) R_3 \Rightarrow$

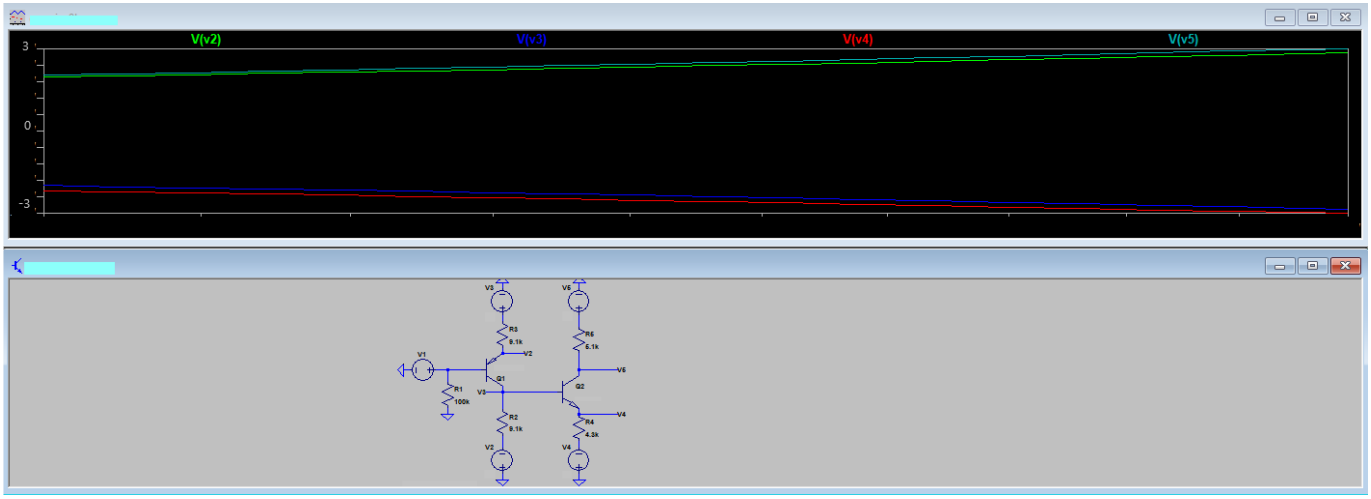
$\Rightarrow V_5 = 3V - 0,315 \cdot 10^{-3}\left(\dfrac{100}{101}\right) \cdot 51 \cdot 10^3 \Rightarrow V_5 = 1,409V$

Άσκηση 14

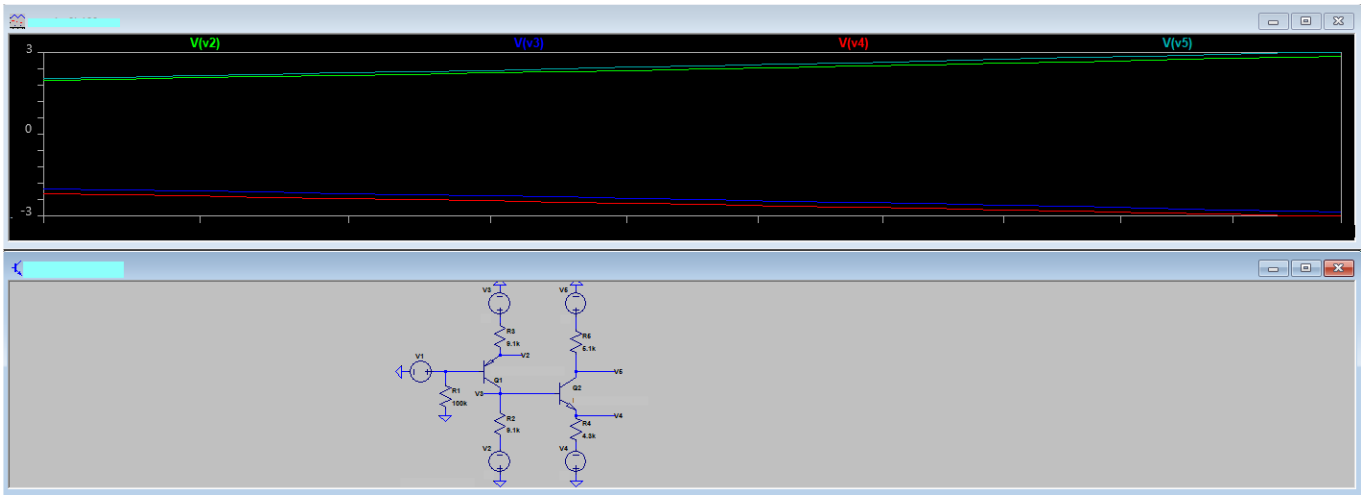
Α. √

Β. Για την ορθή παρουσίαση (και σύνδεση) του pnp transistor έγινε καθρεφτισμός και περιστροφή του, ώστε να τοποθετηθεί σωστά στο κύκλωμα. Έγινε χρήση των μοντέλων 2N2222 και 2N2907.

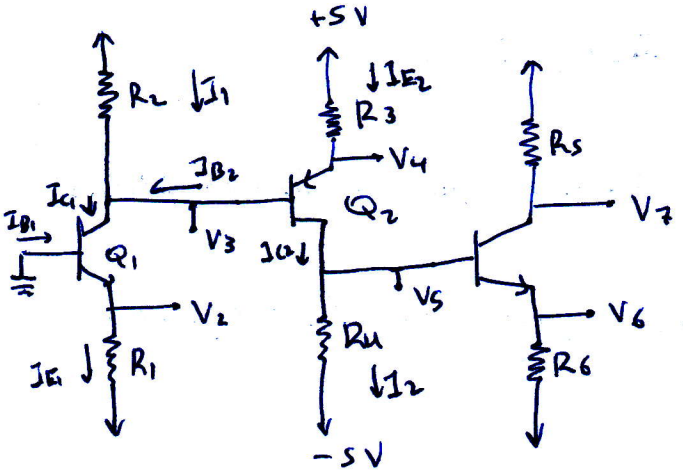
Για β = ∞



Για β =100



Άσκηση 15 (6.67)



$\beta = \infty$, $B = 100$

ρεύτα ναλωσης Q_1, Q_2, Q_3 είναι 0,5mA, 0,5mA, 1mA

$V_3 = 0$, $V_5 = -2V$, $V_7 = 1V$

Για $\beta = \infty$:

$I_{B1} = 0$, $I_{B2} = 0$, $I_{B3} = 0$

$V_2 = V_{B1} - V_{BE1} = 0 - 0,7V = -0,7V$

$I_1 = \dfrac{V_2 - (-5V)}{R_1} \Rightarrow R_1 = \dfrac{V_2 + 5V}{I_1} = \dfrac{-0,7 + 5V}{0,5mA} = 8,6K\Omega \rightarrow R_1 = 8,2K\Omega$

$V_4 = V_{B2} + V_{BE2} = 0 + 0,7V = 0,7V$

$R_3 = \dfrac{5 - V_4}{I_{E2}} = \dfrac{5 - 0,3V}{0,5} = 8,6K\Omega \rightarrow R_3 = 8,2K\Omega$

$R_4 = \dfrac{V_5 - (-5V)}{I_{C2}} = \dfrac{-2V + 5V}{0,5mA} = 6K\Omega \rightarrow R_4 = 6K\Omega$

$V_6 = V_5 - V_{BE3} = -2V - 0,7V = -3,7V$

$R_6 = \dfrac{V_6 - (-5V)}{I_{E3}} = \dfrac{-2,7 + 5V}{I_{E3}} = \dfrac{2,3V}{1mA} = 2,3K\Omega \rightarrow R_6 = 2,4K\Omega$

$R_5 = \dfrac{5V - V_7}{I_{C3}} = \dfrac{5V - 1V}{1mA} = 4K\Omega \rightarrow R_5 = 3,9K\Omega$

Για $\beta = 100$:

$V_2 = V_{B1} - 0,7V = 0 - 0,7V = -0,7V$

$I_{E1} = \dfrac{-0,7V + 5V}{8,2K\Omega} = 0,524mA$

$I_{C1} = \dfrac{\beta}{\beta+1} I_{E1} = \dfrac{100}{101}(0,524mA) = 0,52mA$

$I_1 = I_{C1} - I_{B2} = I_{C1} - \dfrac{I_{E2}}{\beta+1} = 0,52 - 0,01 I_{E2}$ (1)

NTK : $-5V + I_1(10K\Omega) - V_{BE_2} - I_{E_2}(8,2K\Omega) + 5V = 0 \Rightarrow$

$\Rightarrow \quad 10 I_1 = 8,2 I_{E_2} + 0,7 \Rightarrow I_1 = 0,82 I_{E_2} + 0,07 \quad (2)$

(1) $\overset{(2)}{\Rightarrow}$ $0,82 I_{E_2} + 907 = 9,52 - 0,01 I_{E_2} \Rightarrow 0,83 I_{E_2} = 0,45 \Rightarrow I_{E_2} = 0,54 mA$

$V_4 = 5V - V_R(8,2K\Omega) = 5V - 8,2K\Omega(I_{E_2}) = 5V - 8,2.10^3(0,54.10^{-3}) = 0,572V$

$V_3 = V_4 - 0,7 = -0,13V$

$I_{C_2} = \frac{\beta}{\beta+1} I_{E_2} = \frac{100}{101} I_{E_2} = \frac{100}{101} \cdot 0,54mA = 0,53mA$

$I_{C_2} = I_2 + I_{B_3} = I_2 + \frac{I_{E_3}}{\beta+1} \Rightarrow I_2 = 953 - 0,01 I_{E_3} \quad (3)$

NTK: $5V - 6,2(I_2) + 0,7V + 2,4(I_{E_3}) - 5V = 0 \Rightarrow$

$\Rightarrow 2,4 I_{E_3} = 6,2 I_2 - 0,7 \Rightarrow I_{E_3} = 2,58 I_2 - 0,29 \quad (4)$

(3) $\overset{(4)}{\Rightarrow}$ $I_2 = 0,53 - 0,01(2,58 I_2 - 0,29) \Rightarrow$

$\Rightarrow I_2 = 0,53 - 0,0258 I_2 + 0,0024 \Rightarrow 1,0258 I_2 = 0,5324 \Rightarrow$

$\Rightarrow I_2 = 0,519 mA \quad$ ou $\quad I_{E_3} = 1,05 mA$

$V_6 = -5 + I_{E_3}(2,4K\Omega) = -5 + 1,05mA(2,4K\Omega) = -2,48V$

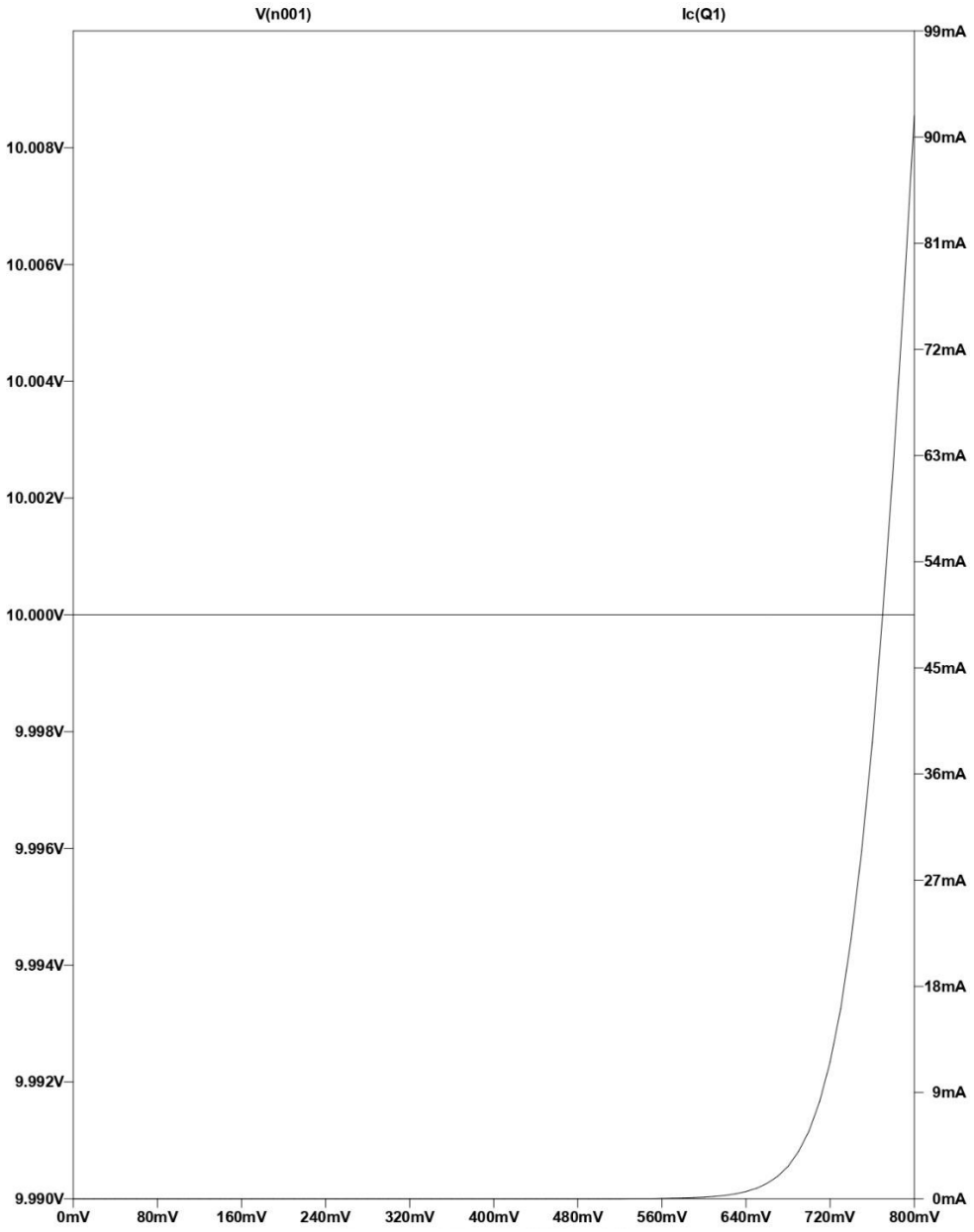
$V_5 = V_6 + V_{BE_3} = -2,48V + 0,7 = -1,78V$

$I_{C_3} = \frac{\beta}{\beta+1} I_{E_3} = \frac{100}{101}(1,05mA) = 1,04mA$

$V_7 = 5 - I_{C_3}.(3,9K\Omega) = 5 - 1,04mA(3,9K\Omega) = 9V$

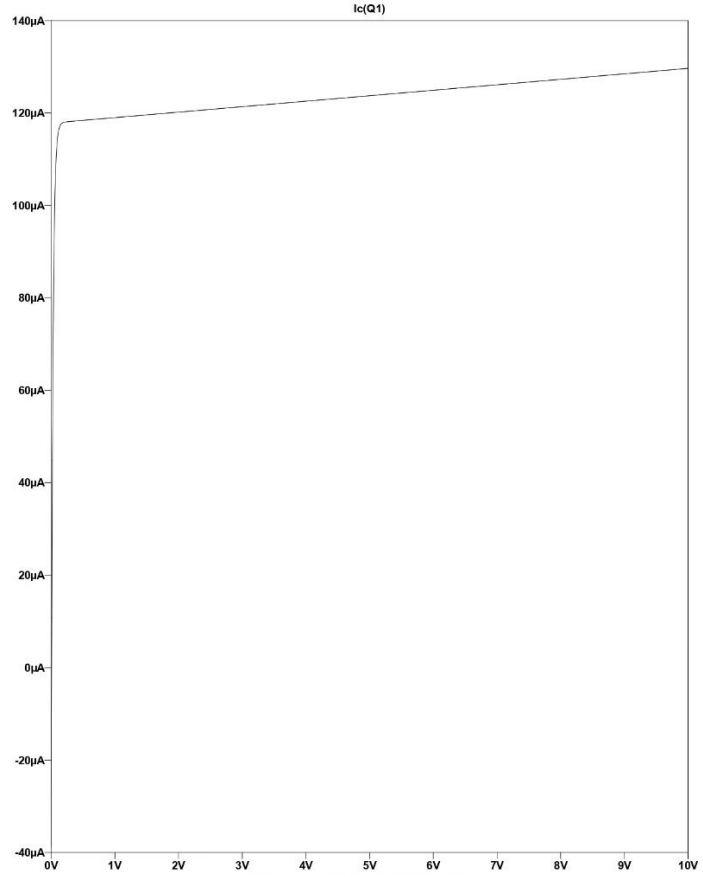
Άσκηση 16

Α. Μόνο όταν περάσει το V_{BE} την τιμή των 0,64-0,7 V διέρχεται ρεύμα από τον συλλέκτη. Επομένως, τότε είναι που το τρανζίστορ λειτουργεί στην ενεργό περιοχή.

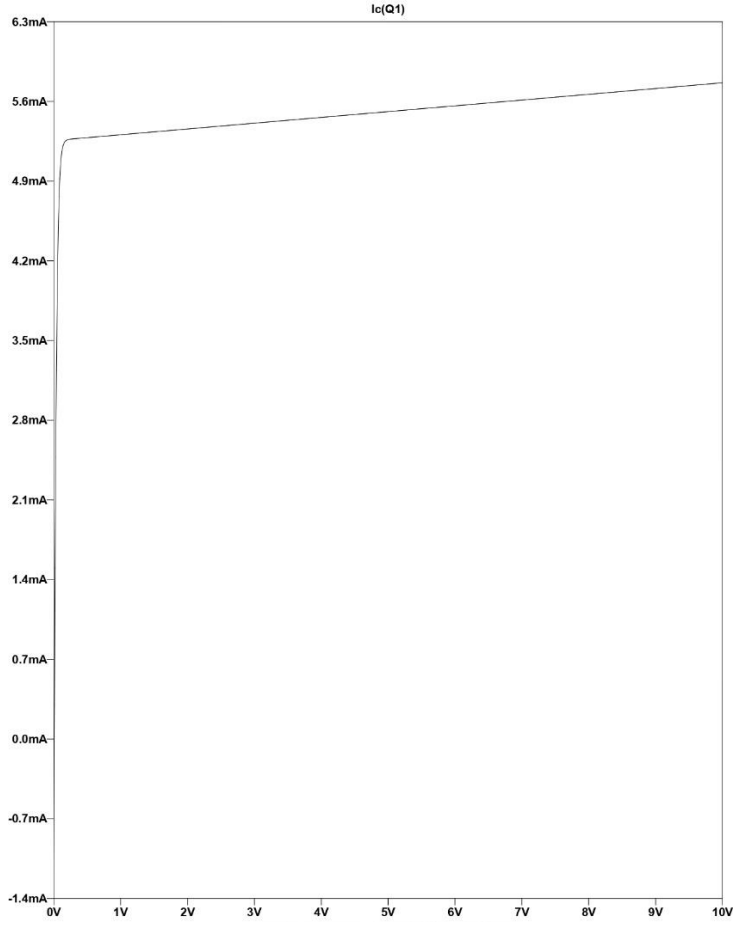


B. Υπάρχουν οι εξής περιπτώσεις:

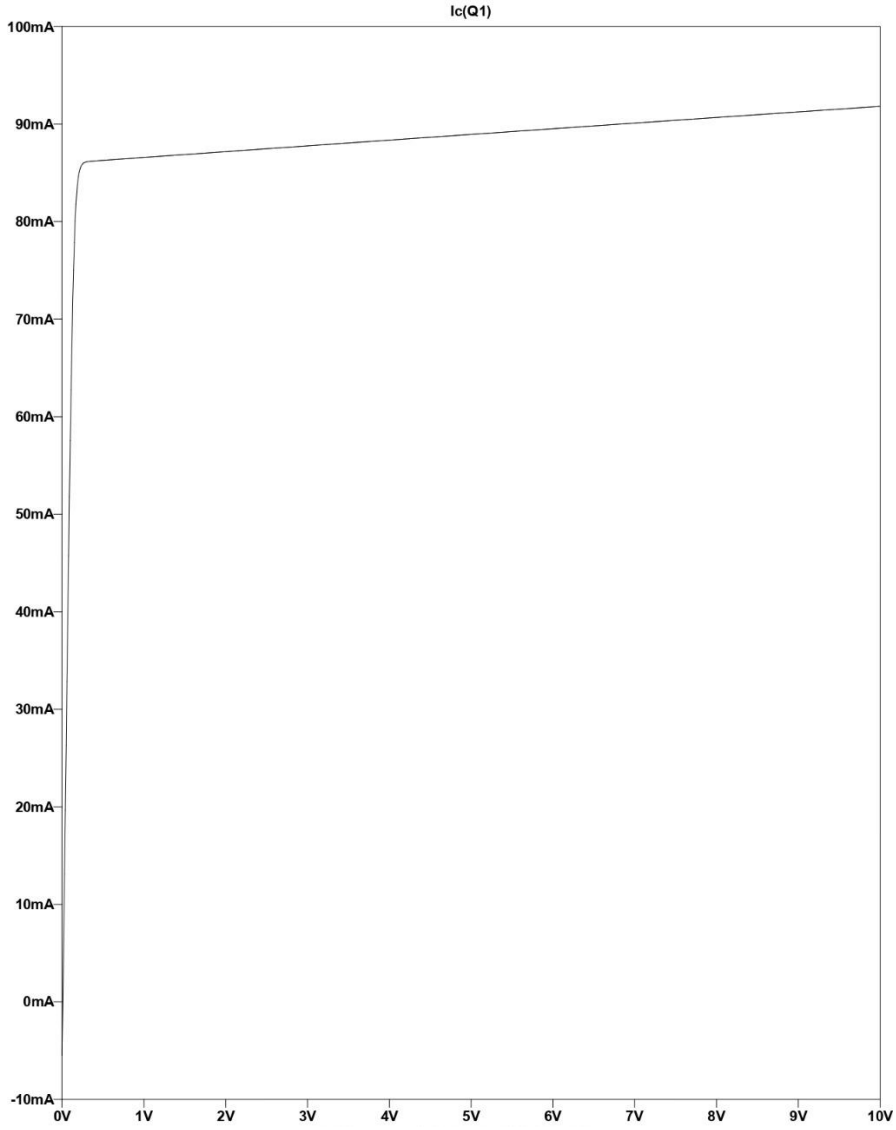
i. V_{BE} = 0,6 V



ii. V_{BE} = 0,7 V



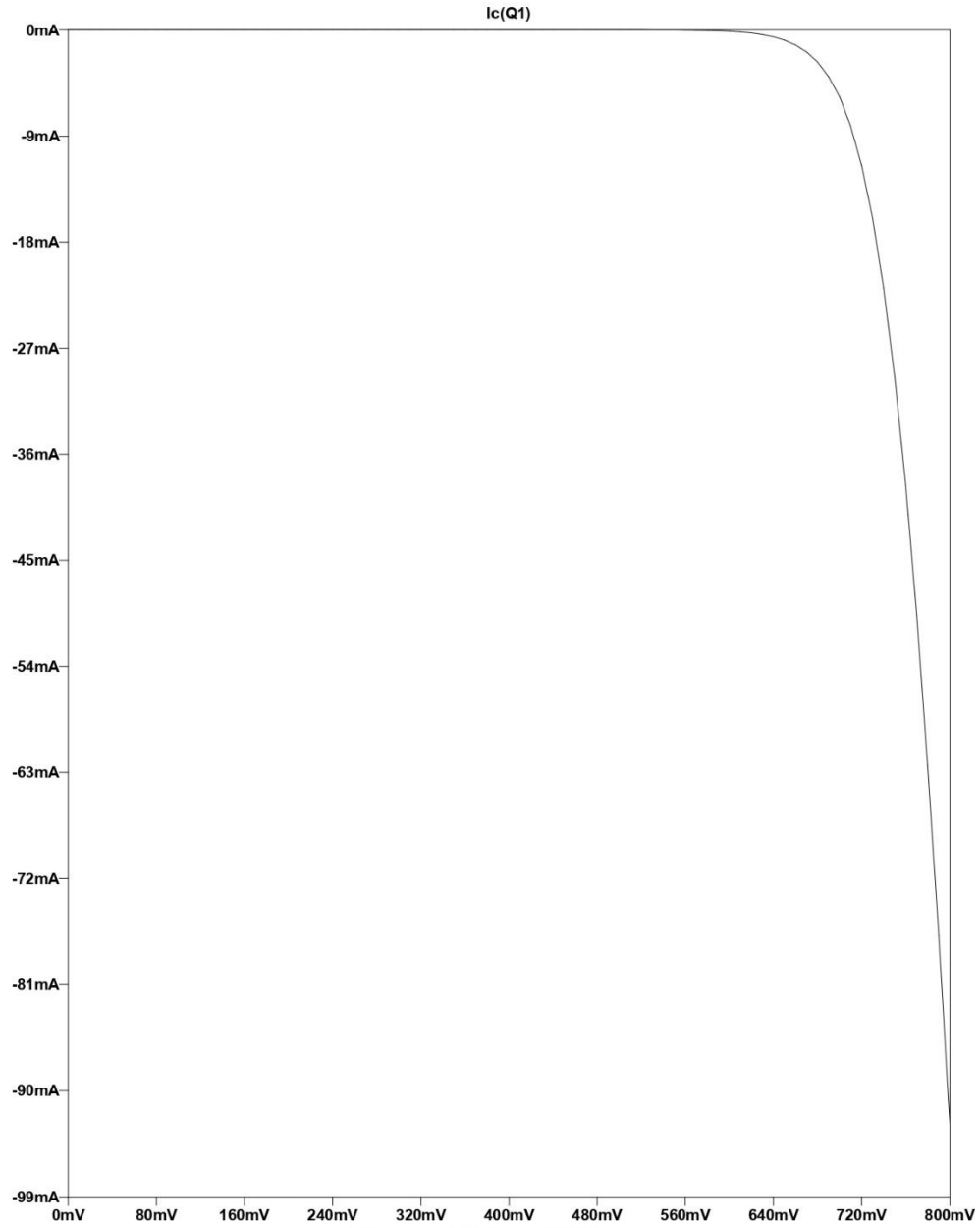
iii. V_{BE} = 0,8 V



Όσο αυξάνεται η τιμή της V_{BE}, η μέγιστη τιμή του ρεύματος του συλλέκτη αυξάνεται. Αυτό είναι αναμενόμενο, γιατί από την θεωρία το exp(V_{BE}/Vt) είναι ανάλογο του Ic.

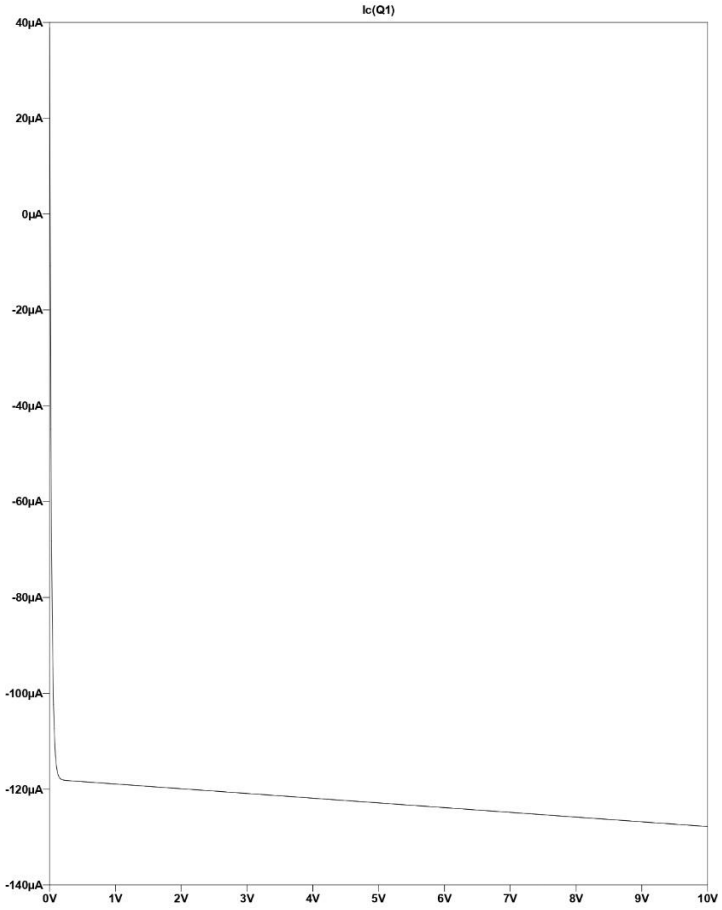
Άσκηση 17

A. Ρεύμα αρχίζει να διέρχεται από το συλλέκτη προς το υπόλοιπο κύκλωμα μόνο όταν η V_{EB} φτάσει στα 0.64 - 0.7 V. Τότε, όπως είναι προφανές, το τρανζίστορ αρχίζει να λειτουργεί στην ενεργό περιοχή.

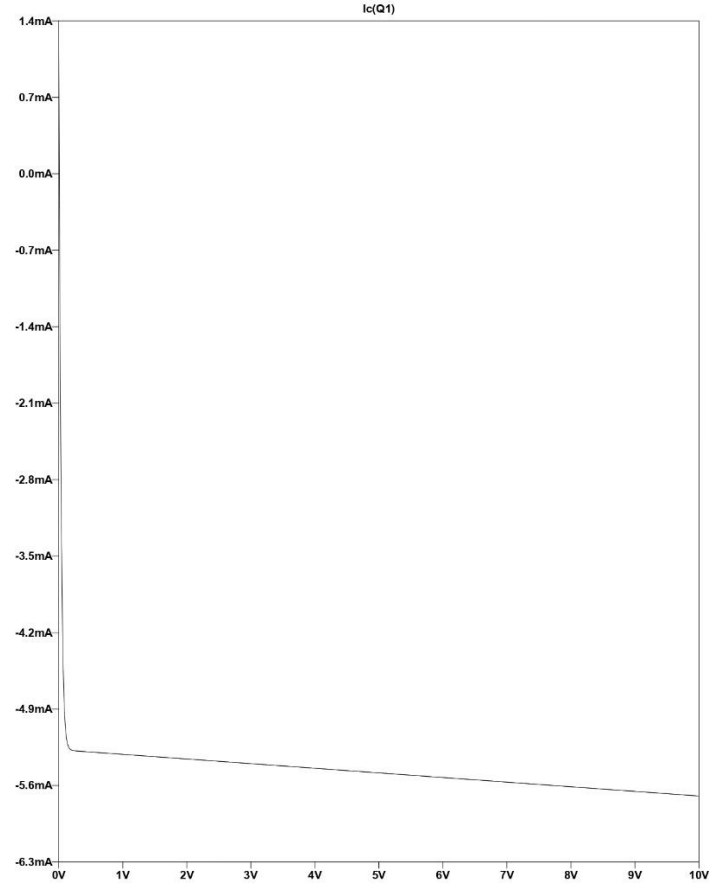


Β. Υπάρχουν οι εξής περιπτώσεις:

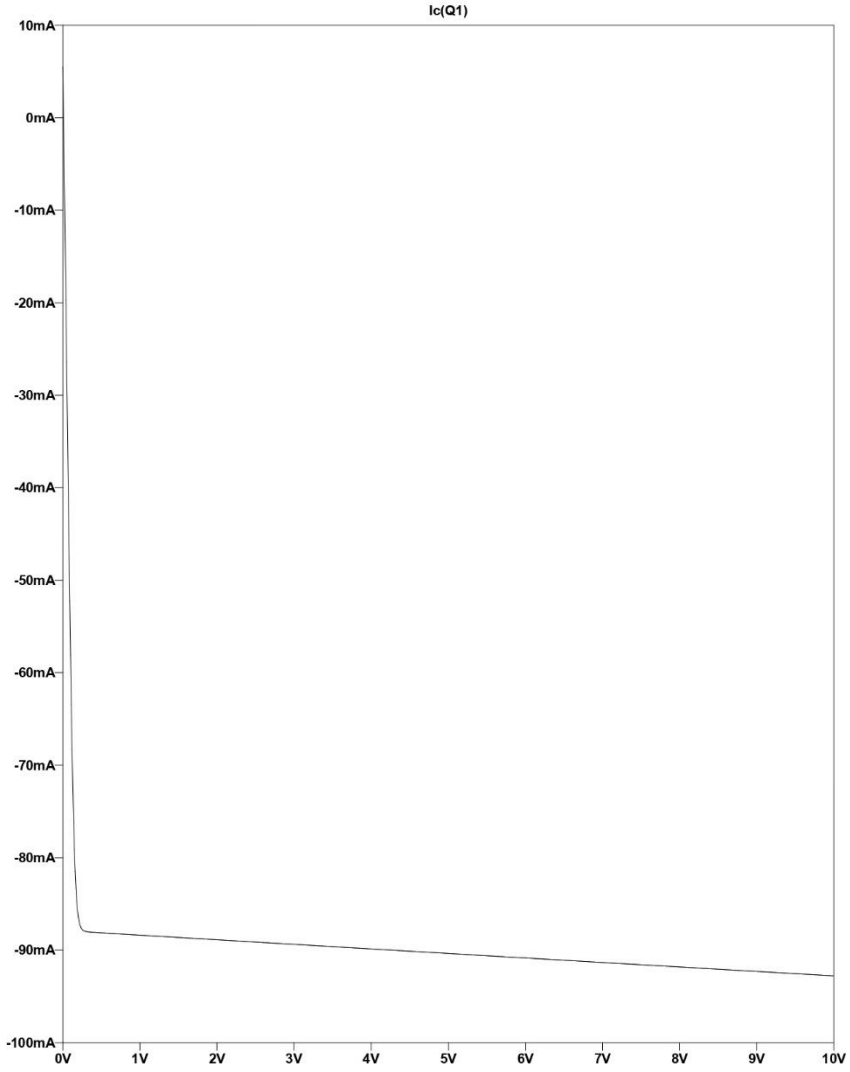
i. V_{EB} = 0,6 V



ii. V_{EB} = 0,7 V



iii. V_{EB} = 0,8 V



Όσο αυξάνεται το V_{EB} η τιμές του Ic μεγαλώνουν προς τα αρνητικά. Αυτό συμβαίνει γιατί από την θεωρία το exp(V_{EB}/Vt) είναι ανάλογο του Ic. Το αρνητικό πρόσημο υποδηλώνει ότι το ρεύμα εξέρχεται από τον συλλέκτη στο υπόλοιπο κύκλωμα.

Άσκηση 18

$$\left.\begin{aligned} i_{C1} &= I_S \cdot \exp\left(\frac{V_{B1E}}{V_T}\right) = I_S \cdot \exp\left(\frac{V_{B1}-V_E}{V_T}\right) \\ i_{C2} &= I_S \cdot \exp\left(\frac{V_{B2E}}{V_T}\right) = I_S \cdot \exp\left(\frac{V_{B2}-V_E}{V_T}\right) \end{aligned}\right\} \Rightarrow \frac{i_{C1}}{i_{C2}} = \exp\left(\frac{V_{B1}-V_E-(V_{B2}-V_E)}{V_T}\right) \Rightarrow$$

$$\Rightarrow \frac{i_{C1}}{i_{C2}} = \exp\left(\frac{V_{B1}-V_{B2}}{V_T}\right) \quad (1), \qquad \frac{i_{E1}}{i_{E2}} = \exp\left(\frac{V_{B1}-V_{B2}}{V_T}\right) \quad (2)$$

$V_{B1} - V_{B2} = V_{id}$, $V_{C1} - V_{C2} = V_{od}$

$$(1) \Rightarrow i_{C1} = i_{C2} \cdot \exp\left(\frac{V_{B1}-V_{B2}}{V_T}\right) \quad (3)$$

$$(1) \Rightarrow i_{C2} = i_{C1} \cdot \exp\left(-\frac{V_{B1}-V_{B2}}{V_T}\right) \quad (4)$$

ΡΚ Ε: $i_{E1} + i_{E2} = I \overset{\alpha=1}{\Longleftrightarrow} i_{C1} + i_{C2} = I \overset{(4)}{\Rightarrow} i_{C1} + i_{C1} \cdot \exp\left(-\frac{V_{B1}-V_{B2}}{V_T}\right) = I \Rightarrow$

$$\Rightarrow i_{C1} = \frac{I}{1+\exp\left(-\frac{V_{B1}-V_{B2}}{V_T}\right)} \quad (5)$$

Ρoίως, $i_{C1} + i_{C2} = I \overset{(3)}{\Rightarrow} i_{C2} = \dfrac{I}{1+\exp\left(\frac{V_{B1}-V_{B2}}{V_T}\right)}$ (6)

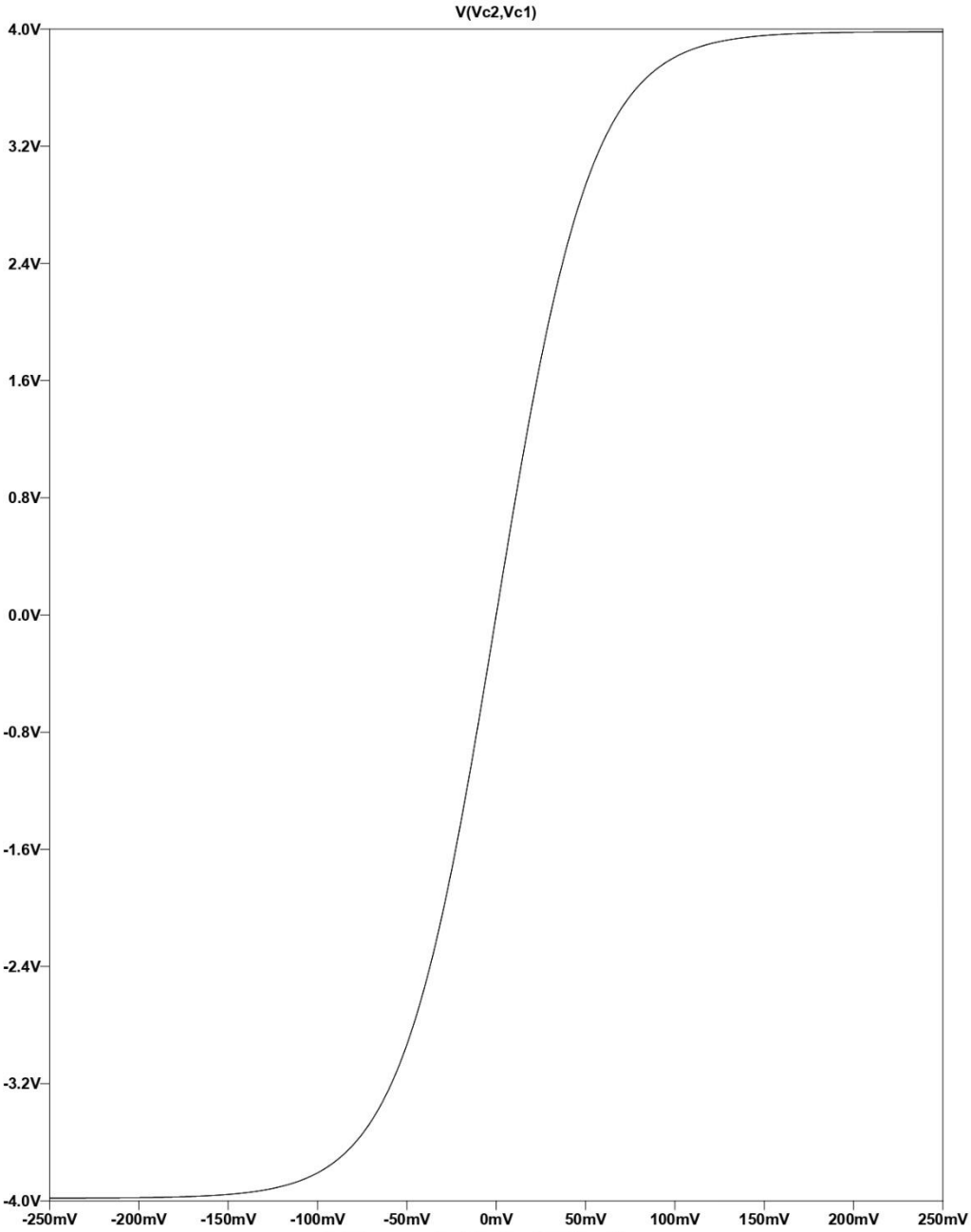
$$(5) \overset{(6)}{\Rightarrow} i_{C1} = \frac{I \exp\left(\frac{V_{B1}-V_{B2}}{V_T}\right)}{1+\exp\left(\frac{V_{B1}-V_{B2}}{V_T}\right)} \quad (7)$$

$$(6) \overset{(5)}{\Rightarrow} i_{C2} = \frac{I \exp\left(-\frac{V_{B1}-V_{B2}}{V_T}\right)}{1+\exp\left(-\frac{V_{B1}-V_{B2}}{V_T}\right)} \quad (8)$$

Τέλος, $i_{C1} - i_{C2} \overset{(7)\wedge(8)}{=\!=} I \cdot \tanh\left(\frac{V_{B1}-V_{B2}}{2V_T}\right)$

Άσκηση 18

Β. Η γραφική παράσταση είναι:



Δοκιμή 19

$$I_{C1} = \frac{I_{EE}}{1+\exp\left(-\frac{V_2}{V_T}\right)}, \quad I_{C2} = \frac{I_{EE}}{1+\exp\left(\frac{V_2}{V_T}\right)}$$ (ζεύγος Q_1-Q_{12})

$$I_{C3} = \frac{I_{C1}}{1+\exp\left(-\frac{V_1}{V_T}\right)}, \quad I_{C4} = \frac{I_{C1}}{1+\exp\left(\frac{V_1}{V_T}\right)}$$ (ζεύγος Q_3-Q_4)

$$I_{C5} = \frac{I_{C2}}{1+\exp\left(\frac{V_1}{V_T}\right)}, \quad I_{C6} = \frac{I_{C2}}{1+\exp\left(-\frac{V_1}{V_T}\right)}$$ (ζεύγος Q_5-Q_6)

$$\Delta I = I_{C3} + I_{C5} - (I_{C4} + I_{66})$$

$$\Delta I = I_{EE} \cdot \tanh\left(\frac{V_1}{2V_T}\right) \tanh\left(\frac{V_2}{2V_T}\right)$$

(Παλμός Gilbert).