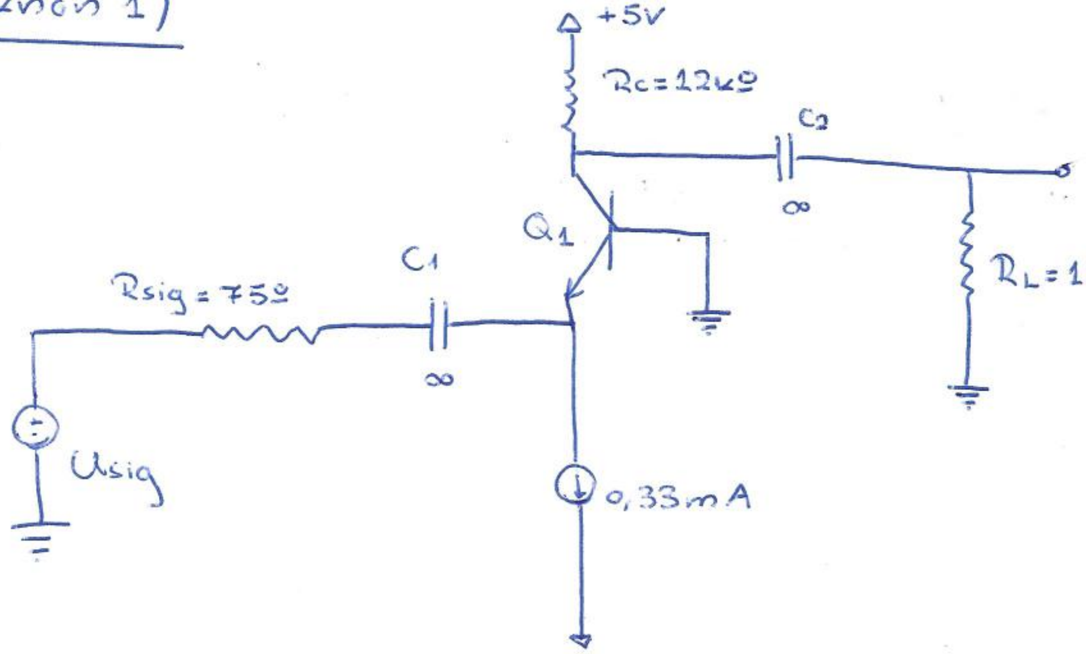
# Πεολίδης Αχιλλέας

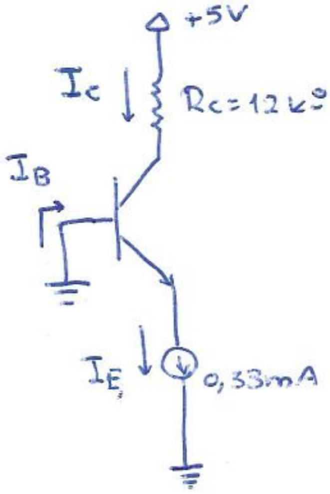
el16604 εξάμηνο: 8ο

# Ηλεκτρονική Ι - 3η Σειρά Ασκήσεων

Ασκηση 1)




DC ανάλυση :




$I_E = 0{,}33mA$

$I_C = a \cdot I_E = 0{,}99 \cdot 0{,}33mA = 0{,}327mA$

$a = \frac{B}{B+1} \Rightarrow \frac{B}{B+1} = 0{,}99 \Rightarrow \beta \doteq 99$

$I_C = B \cdot I_B \Rightarrow I_B = \frac{I_C}{\beta} = \frac{0{,}327mA}{99} =$

$= 0{,}0033mA$

$5 - V_C = I_C R_C \Rightarrow V_C = 5 - I_C R_C =$

$= 5 - (0{,}327mA) \cdot (12k\Omega) = 1{,}076V$

Άρα έχουμε:

$I_E = 0{,}33\,mA$

$I_C = 0{,}327\,mA$

$I_B = 0{,}0033\,mA$

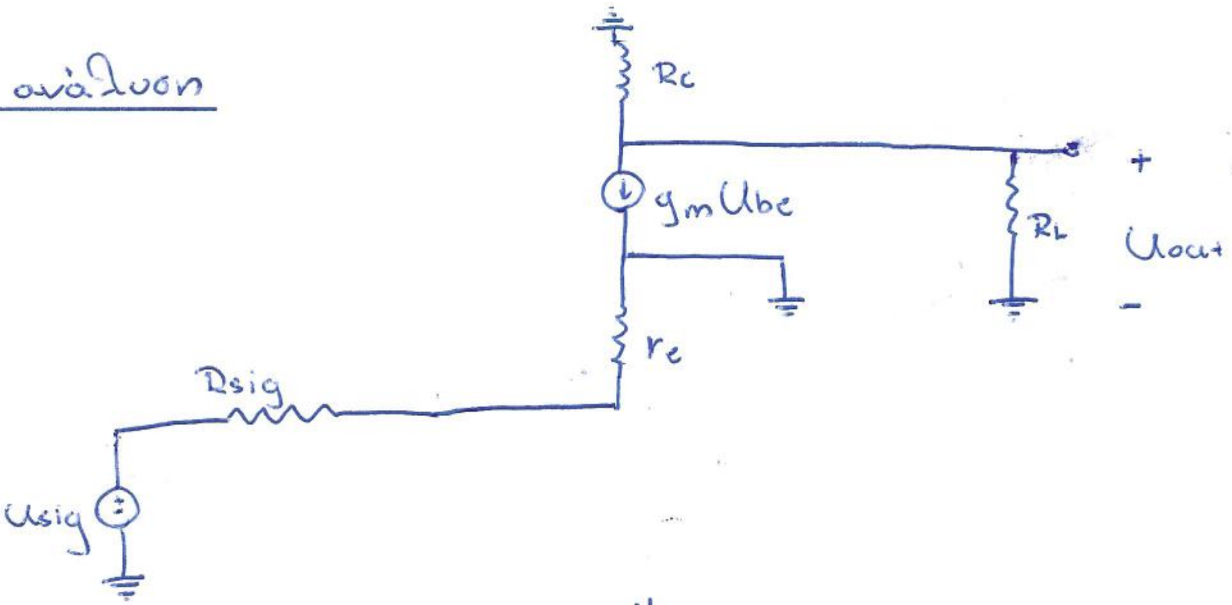
$V_C = 1{,}076\,V$

$$r_\pi = \frac{V_T}{I_B} = \frac{25\,mV}{0{,}0033\,mA} = 7575{,}76\,\Omega$$

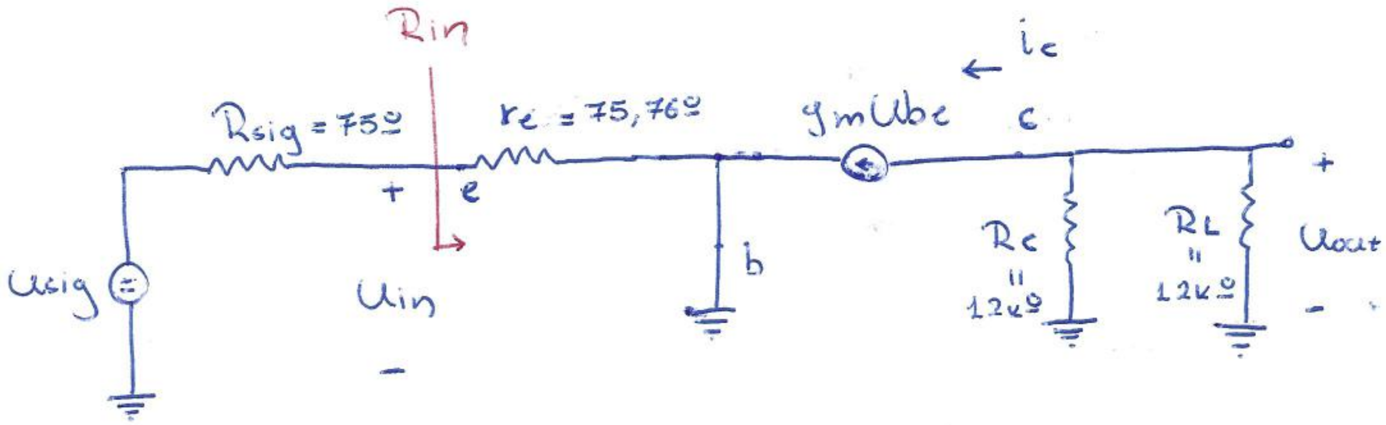
$$g_m = \frac{I_C}{V_T} = \frac{0{,}327\,mA}{25\,mV} = 0{,}013$$

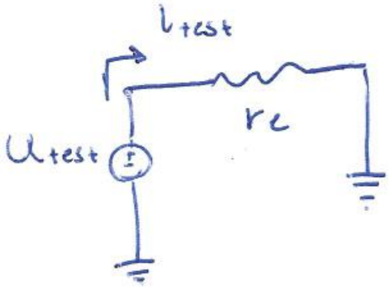
$$r_e = \frac{V_T}{I_E} = \frac{25\,mV}{0{,}33\,mV} = 75{,}76\,\Omega$$

## AC ανάλυση




⇓




$$\boxed{R_{in} = \frac{U_{test}}{i_{test}} = r_e}$$

$$U_{out} = -(R_C // R_L) \cdot i_c \quad (1)$$

$$U_{in} = U_{sig} \cdot \frac{r_e}{R_{sig} + r_e} \quad (2)$$

$$\left.\begin{array}{l} u_{bc} = -u_{eb} = -u_{in} \\ i_c = g_m \cdot u_{be} = -g_m \cdot u_{eb} \end{array}\right\} i_c = -g_m u_{in}$$

$$\xrightarrow{(1)} u_{out} = -(R_C // R_L)(-g_m \cdot u_{in})$$

$$\overset{(2)}{\Rightarrow} u_{out} = -(R_C // R_L) \cdot \left(-g_m \cdot u_{sig} \cdot \frac{r_e}{R_{sig} + r_e}\right) \Rightarrow$$

$$\Rightarrow \frac{u_{out}}{u_{sig}} = -\frac{R_C R_L}{R_C + R_L} \cdot (-g_m) \cdot \frac{r_e}{R_{sig} + r_e} \Rightarrow$$

$$\Rightarrow \frac{u_{out}}{u_{sig}} = \frac{R_C R_L}{R_C + R_L} \cdot g_m \cdot \frac{r_e}{R_{sig} + r_e} =$$

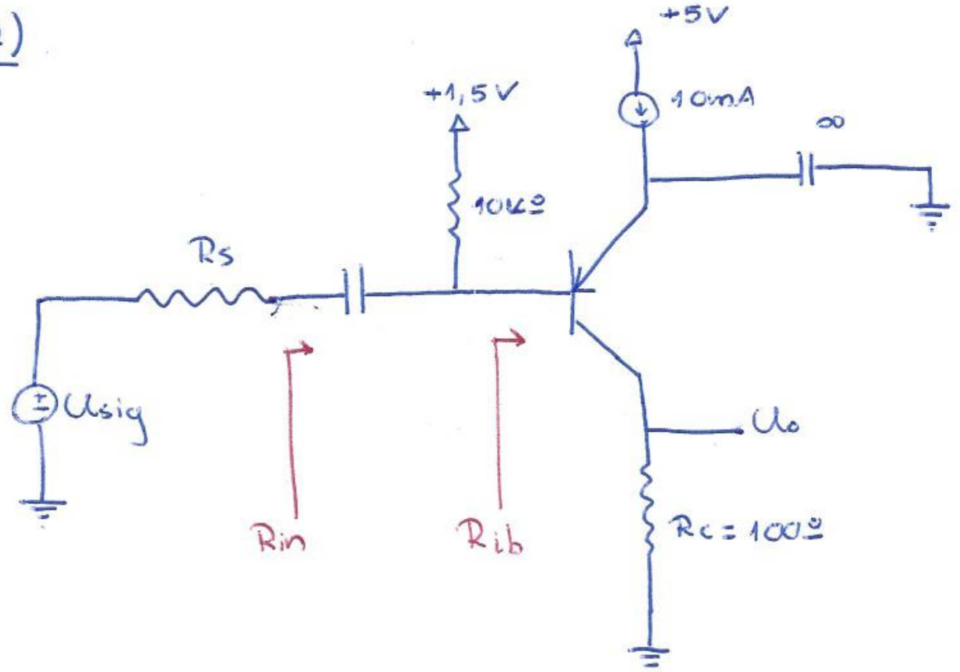
$$= \frac{(12k\Omega)(12k\Omega)}{12k\Omega + 12k\Omega} \cdot 0{,}013 \cdot \frac{75{,}76\Omega}{75\Omega + 75{,}76\Omega} = 39{,}2$$

$$\Rightarrow \boxed{\frac{u_{out}}{u_{sig}} = 39{,}2}$$

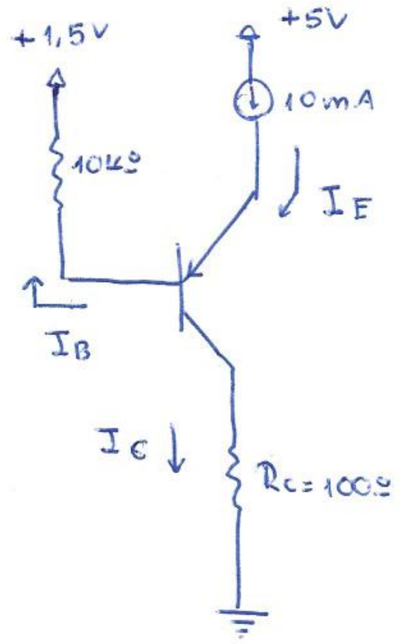
Σημείωση: Παρατηρώντας πως ο ενισχυτής μας είναι κοινής βάσης μπορούμε κατευθείαν να πούμε:

- $R_{in} = r_e$
- $\frac{u_{out}}{u_{sig}} = \frac{a(R_C // R_L)}{R_{sig} + r_e}$

## Άσκηση 2)




## DC ανάλυση




$I_E = 10mA \quad , \quad \beta = 200$

$I_E = (\beta+1) I_B \Rightarrow I_B = \frac{I_E}{201} = \frac{10mA}{201} = 0,05mA$

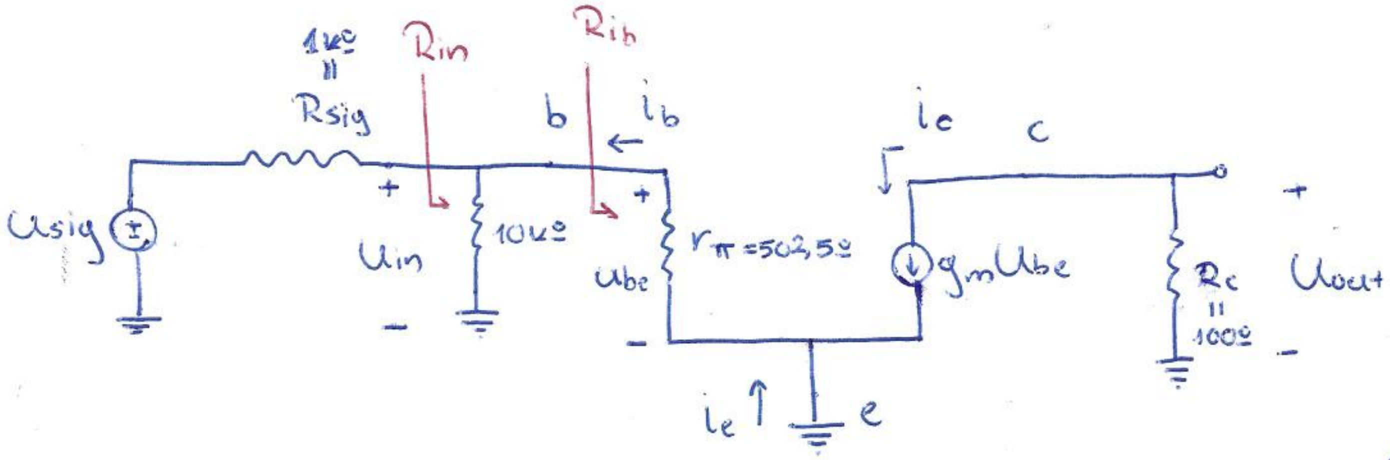
$I_C = \beta \cdot I_B = 200 \cdot 0,05mA = 9,95\,mA$

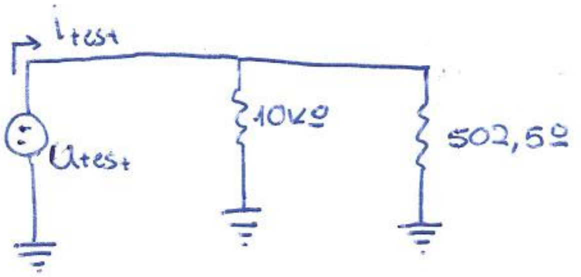
$V_C = R_C I_C = 100 \cdot 9,95mA = \boxed{0,995A}$

Άρα:

- $g_m = \frac{I_C}{V_T} = \frac{9,95mA}{25\,mV} = 0,398$
- $r_\pi = \frac{V_T}{I_B} = \frac{25mV}{0,05mA} = 502,5\,\Omega$

## AC ανάλυση






$$R_{in} = \frac{U_{test}}{i_{test}}$$

$$R_{in} = \frac{10k\Omega \cdot 502,5\Omega}{10k\Omega + 502,5\Omega} = \boxed{478,46\Omega}$$

$$\boxed{R_{ib} = r_\pi = 502,5\Omega}$$

$U_{out} = -i_c \cdot R_c = -g_m U_{be} R_c \ (1)$

$U_{be} = U_{in}$: Τάση στα άκρα της $R_{in}$.

$$U_{be} = \frac{R_{in}}{R_{in}+R_{sig}} \cdot U_{sig} \xrightarrow{(1)} U_{out} = -g_m \cdot \frac{R_{in}}{R_{in}+R_{sig}} \cdot U_{sig} \cdot R_c$$

$$\Rightarrow \frac{U_{out}}{U_{sig}} = -g_m \cdot R_c \cdot \frac{R_{in}}{R_{in}+R_{sig}} = (-0,398) \cdot 100\Omega \cdot \frac{478,46\Omega}{478,46\Omega + 10^3\Omega}$$

$= -12,78$. Άρα $\boxed{\frac{U_{out}}{U_{sig}} = -12,78}$

Σημείωση: Ο ενισχυτής είναι κοινού εκπομπού οπότε μπορούν να χρησιμοποιηθούν και κατευθείαν οι τύποι:

- $R_{in} = r_\pi = (1+\beta) r_e$

- $$\frac{U_{sig}}{U_{out}} = -\beta \cdot \frac{R_c // R_L}{R_{sig} + r_\pi} = \frac{R_c // R_L}{R_{sig} + (1+\beta) r_e}$$

(στη περίπτωση μας $R_c = R_L$)

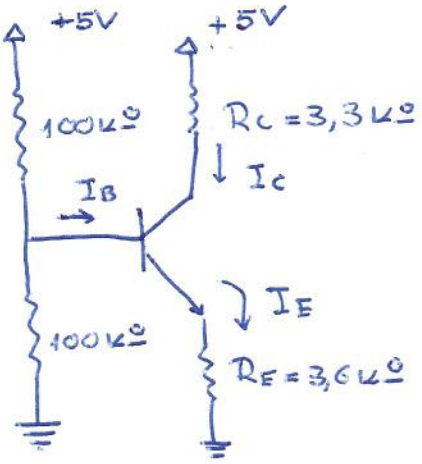
Αν θέλουμε $U_{out} = \pm 0,4V$ τότε $|U_{sig}| = \left|\frac{0,4}{-12,78}\right| = \boxed{0,0313V}$

$$U_{be} = \frac{R_{in}}{R_{in}+R_{sig}} \cdot U_{sig} = \frac{478,46}{478,46 + 10^3} \cdot 0,0313 = \boxed{0,01V}$$

## Άσκηση 3)

## Σχήμα Π 7.58 Sedra Smith

### DC ανάλυση:




$B = \infty \Rightarrow I_B = 0$ κ' $I_C = I_E$

$$V_B = \frac{100k\Omega}{100k\Omega + 100k\Omega} \cdot 5V = 2,5V$$

$$V_E = 2,5 - 0,7 = 1,8V$$

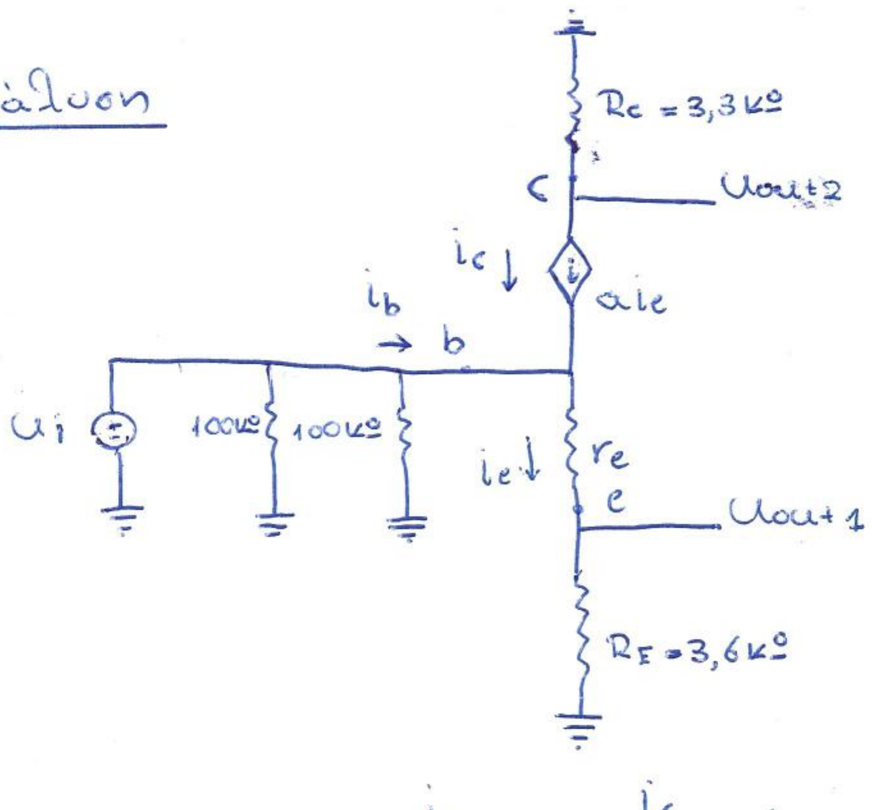
$$I_E = \frac{1,8V}{3,6k\Omega} = 0,5mA = I_C$$

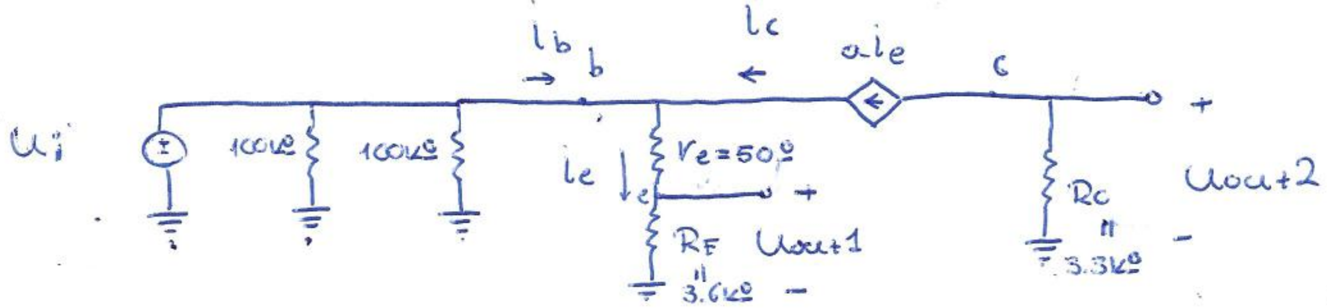
$$V_C = 5V - 3,3k\Omega \, 0,5mA = 3,35V$$

- $g_m = \dfrac{I_C}{V_T} = \dfrac{0,5mA}{25mV} = 0,02$

- $r_e = \dfrac{V_T}{I_E} = \dfrac{25mV}{0,5mA} = 50\Omega$

### AC ανάλυση



$i_b = 0$ συνεπώς οι αντιστάσεις $100k\Omega$ δεν διαρρέονται από ρεύμα και η τάση στο σημείο b είναι $U_b = U_i$. Έτσι έχουμε:

$$U_{out1} = \frac{R_E}{R_E + r_e} \cdot U_i \Rightarrow \boxed{\frac{U_{out1}}{U_i} = \frac{R_E}{R_E + r_e}}$$

$$\left.\begin{aligned} U_{out2} &= -a i_e \cdot R_C \\ i_e &= \frac{U_i}{R_E + r_e} \end{aligned}\right\} U_{out2} = -a \cdot \frac{U_i}{R_E + r_e} \cdot R_C \Rightarrow \boxed{\frac{U_{out2}}{U_i} = \frac{-a R_C}{R_E + r_e}}$$

$$\frac{U_{out1}}{U_i} = \frac{3{,}6k\Omega}{50\Omega + 3{,}6k\Omega} = \boxed{0{,}986}$$

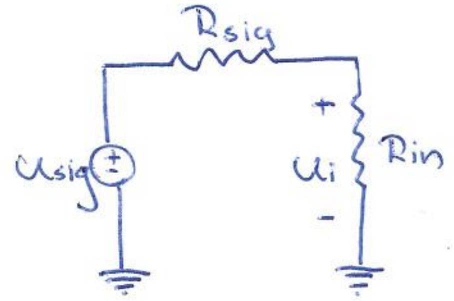
$$\frac{U_{out2}}{U_i} = -\frac{1 \cdot 3{,}3k\Omega}{50\Omega + 3{,}6k\Omega} = \boxed{-0{,}904}$$

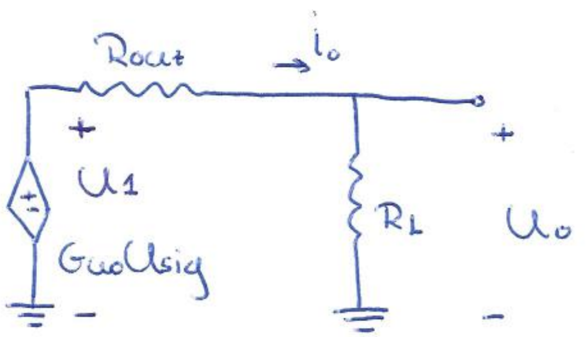
Εαν ο ακροδέκτης $U_{o1}$ γειωθεί:

$$i_e = \frac{U_i}{r_e} \rightarrow U_{out2} = -a \cdot \frac{U_i}{r_e} \cdot R_C \Rightarrow \boxed{\frac{U_{out2}}{U_{in}} = -a \cdot \frac{R_C}{r_e}} =$$

$$= -1 \cdot \frac{3{,}3k\Omega}{3{,}6k\Omega} = \boxed{-0{,}92}$$

## Άσκηση 4)




Για $R_L = \infty$ η $R_L$ δεν διαρρέεται από ρεύμα και έχουμε το κέρδος ανοιχτού βρόγχου: $G_{\upsilon o} = \left.\dfrac{\upsilon_o}{\upsilon_{sig}}\right|_{R_L \to \infty}$ (1)

$\upsilon_o = \upsilon_1$

$$A_{\upsilon o} = \frac{\upsilon_o}{\upsilon_{in}} \Rightarrow \upsilon_o = A_{\upsilon o} \cdot \upsilon_{in} \xrightarrow{(1)} G_{\upsilon o} = \frac{A_{\upsilon o} \cdot \upsilon_{in}}{\upsilon_{sig}} \Rightarrow$$

$$\Rightarrow G_{\upsilon o} = \frac{\upsilon_{in}}{\upsilon_{sig}} \cdot A_{\upsilon o} \quad (2).$$

$$\upsilon_i = \frac{R_{in}}{R_{in} + R_{sig}} \cdot \upsilon_{sig} \Rightarrow \frac{\upsilon_i}{\upsilon_{sig}} = \frac{R_{in}}{R_{in} + R_{sig}}$$

$$\xrightarrow{(2)} \boxed{G_{\upsilon o} = \frac{R_{in}}{R_{in} + R_{sig}} \cdot A_{\upsilon o}}$$

Συνολικό κέρδος τάσης: $G_\upsilon = \dfrac{\upsilon_o}{\upsilon_{sig}}$

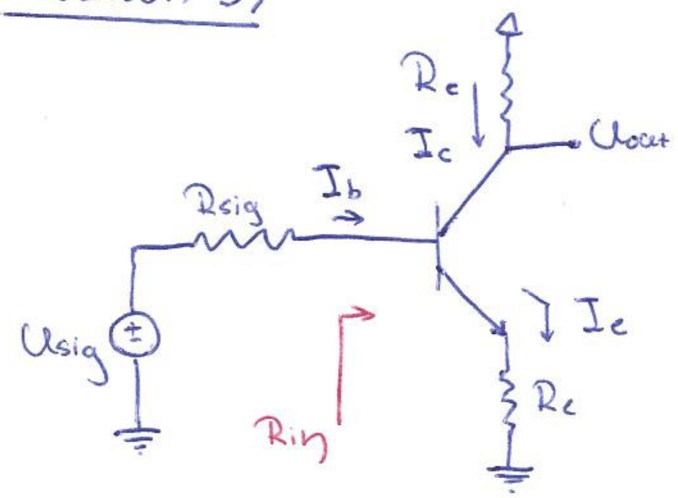
$$\left.\begin{aligned} G_\upsilon &= \frac{\upsilon_o}{\upsilon_{sig}} \\ G_{\upsilon o} = \frac{\upsilon_1}{\upsilon_{sig}} &\Rightarrow \upsilon_{sig} = \frac{\upsilon_1}{G_{\upsilon o}} \end{aligned}\right\} G_\upsilon = \frac{\upsilon_o}{\frac{\upsilon_1}{G_{\upsilon o}}} \Rightarrow$$

$$\Rightarrow G_\upsilon = \frac{\upsilon_o}{\upsilon_1} \cdot G_{\upsilon o} \quad (3)$$

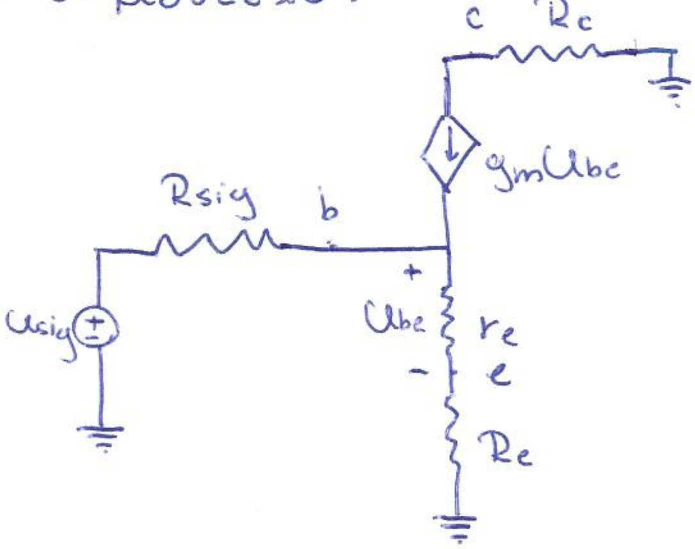
$$u_o = \frac{R_L}{R_L + R_{out}} \cdot u_1 \Rightarrow \frac{u_o}{u_1} = \frac{R_L}{R_L + R_{out}}$$

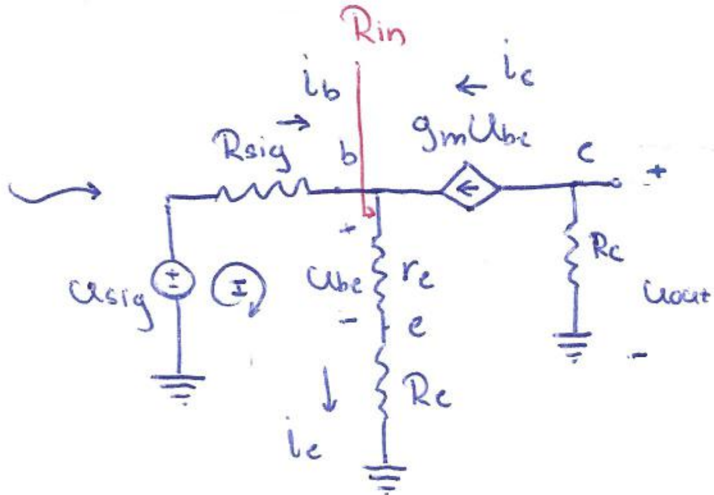
$$\xrightarrow{(3)} \boxed{G_u = \frac{R_L}{R_L + R_{out}} \cdot G_{uo}}$$

## Άσκηση 5)




Εφόσον έχουμε αντίσταση Re επιλέγουμε για την AC ανάλυση το T-μοντέλο:



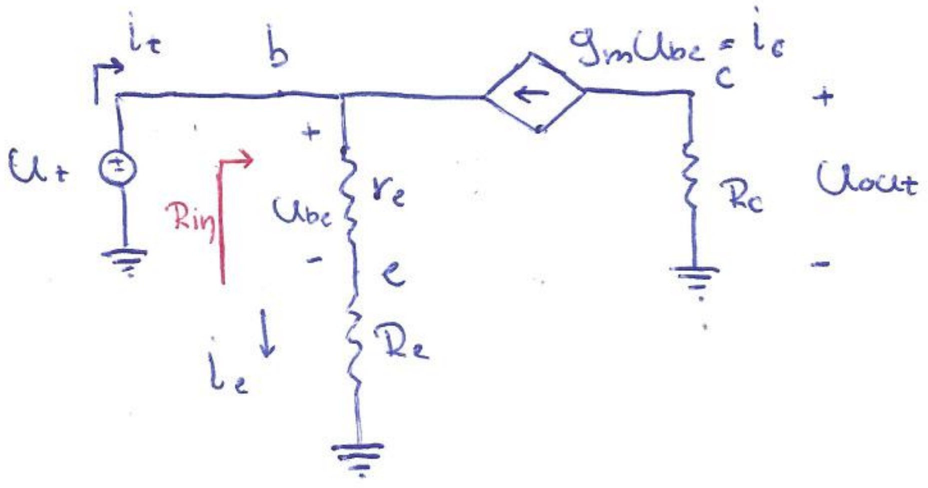

$R_{in} = 15k\Omega$ $\quad\beta = 74$

$U_{sig} = 0,15V$ $\quad R_c = 6k\Omega$

$R_{sig} = 30k\Omega$

$U_{be} = 5mV$

Τοποθετώ δοκιμαστική πηγή αριστερά του ακροδέκτη b :




$$u_t = i_t \cdot R_{in} \Rightarrow R_{in} = \frac{u_t}{i_t} \quad (1)$$

$$i_t = i_b \,, \quad i_e = (\beta+1)\cdot i_b = (\beta+1)\cdot i_t$$

$$u_t = i_e \cdot (r_e + R_e) = (\beta+1)\cdot i_t (r_e + R_e)$$

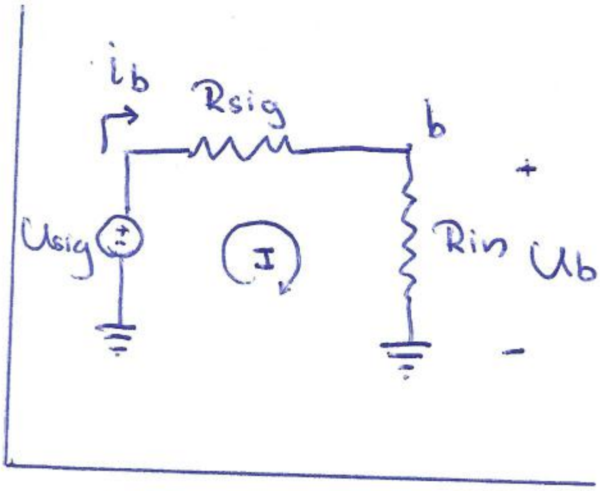
$$\xrightarrow{(1)} R_{in} = \frac{(\beta+1)\cdot \cancel{i_t}(r_e+R_e)}{\cancel{i_t}} = (r_e+R_e)(\beta+1)$$

$$\Rightarrow R_{in} = (r_e+R_e)(\beta+1) \quad (2)$$

Ν.Τ.Κ (I): $-u_{sig} + R_{sig}\cdot i_b + u_b = 0 \Rightarrow$

$$\Rightarrow i_b = \frac{u_{sig} - u_b R_{in}}{R_{sig}} \quad (2)$$

$$u_b = u_{sig}\cdot \frac{R_{in}}{R_{in}+R_{sig}}$$




$$\xrightarrow{(2)} i_b = \frac{u_{sig}\left(1 - \frac{R_{in}}{R_{in}+R_{sig}}\right)}{R_{sig}} =$$

$$\overset{(2)}{=} \frac{u_{sig}\left(1 - \frac{r_e+R_e}{r_e+R_c+R_{sig}}\right)}{R_{ig}}$$

$$= \frac{0{,}15V\left(1 - \frac{15k\Omega}{15k\Omega + 30k\Omega}\right)}{30k\Omega} = 3{,}33\mu A$$

$$i_e = (\beta+1)\,i_b = (74+1)\cdot 3{,}33\mu A = \boxed{0{,}25mA}$$

$$U_b = 0{,}15V \cdot \frac{15k\Omega}{15k\Omega + 30k\Omega} = 0{,}05V$$

$$\cancel{\left.\begin{aligned} U_{be} &= U_b \cdot \frac{r_e}{R_{in}} \\ U_{be} &= i_e \cdot r_e \end{aligned}\right\} i_e \cdot r_e = U_b \cdot \frac{r_e}{R_{in}} \Rightarrow}$$

$$\cancel{\Rightarrow 0{,}25mA \cdot r_e = 0{,}05V \cdot \frac{r_e}{15k\Omega} \Rightarrow r_e =}$$

$$U_{be} = i_e \cdot r_e \Rightarrow r_e = \frac{U_{be}}{i_e} = \frac{5mV}{0{,}25mA} = 20\Omega \Rightarrow \boxed{r_e = 20\Omega}$$

(2)

$$\rightarrow R_{in} = (r_e + R_e)(\beta+1) \Rightarrow r_e + R_e = \frac{R_{in}}{\beta+1} \Rightarrow$$

$$\Rightarrow R_e = \frac{R_{in}}{\beta+1} - r_e = \frac{15k\Omega}{74+1} - 20\Omega \Rightarrow \boxed{R_e = 180\Omega}$$

$$U_{out} = -i_c \cdot R_c = -\alpha i_E \cdot R_c = -\alpha(\beta+1)\cdot i_b \cdot R_c =$$

$$= -\frac{\beta}{\cancel{\beta+1}} \cdot \cancel{(\beta+1)} \cdot R_c \cdot \frac{U_{sig}}{R_{sig}+R_{in}} = -\beta \cdot R_c \cdot \frac{U_{sig}}{R_{sig}+R_{in}} \Rightarrow$$

$$\Rightarrow \frac{u_{out}}{u_{sig}} = -\beta \cdot \frac{R_C}{R_{sig}+R_{in}} = G_v \Rightarrow$$

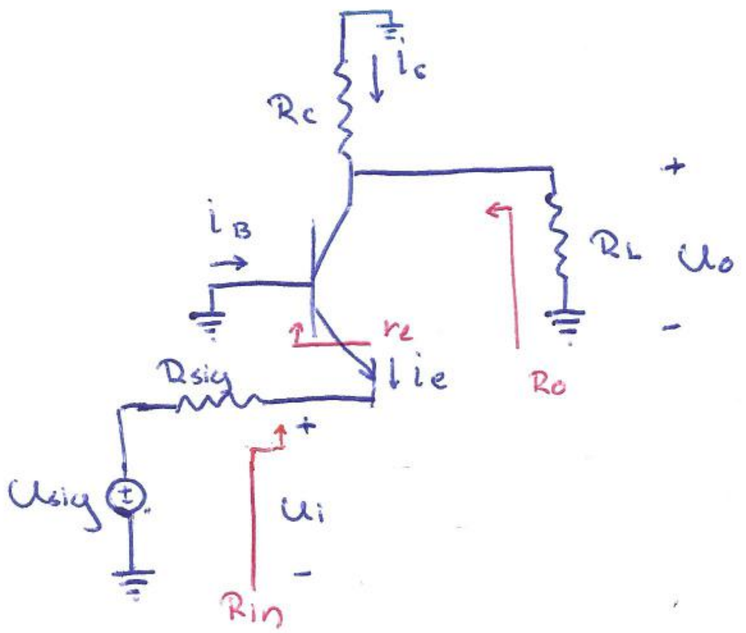
$$\Rightarrow G_v = -77 \cdot \frac{6\,k\Omega}{30\,k\Omega + 15\,k\Omega} \Rightarrow \boxed{G_v = -9{,}87}$$

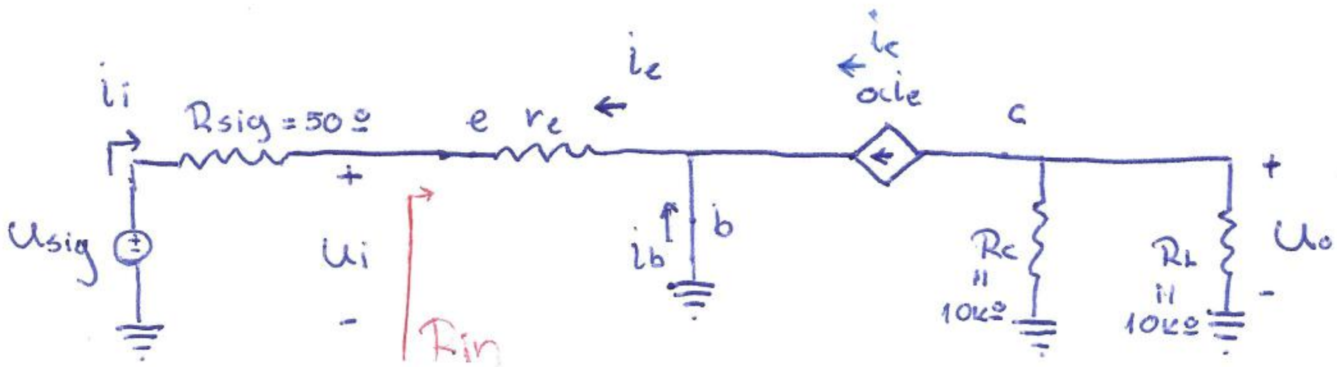
$$u_{out\,max} = -\beta \cdot \frac{R_C}{R_{sig}+R_{in}} \cdot u_{sig\,max} =$$

$$= -9{,}87 \cdot 0{,}15V = \boxed{-1{,}48V : \text{Μέγιστο πλάτος σήματος εξόδου}}$$

Άσκηση 6)

Έχουμε το εξής κύκλωμα: :






$$R_{in} = r_e = 50\Omega$$

$$r_e = \frac{V_T}{I_E} = \frac{\alpha V_T}{I_C} \Rightarrow I_C = \frac{\alpha V_T}{r_e} = \frac{25mV}{50\Omega} = \boxed{0{,}5mA}$$

$$\left.\begin{aligned} U_o &= -i_c \cdot (R_C // R_L) = -\alpha i_e \cdot (R_C // R_L) \\ U_{sig} &= (R_{sig} + r_e) \cdot (-i_e) \Rightarrow i_e = -\frac{U_{sig}}{R_{sig} + r_e} \end{aligned}\right\} \Rightarrow$$

$$\Rightarrow U_o = -\alpha \cdot \left(-\frac{U_{sig}}{R_{sig} + r_e}\right) \cdot (R_C // R_L) \Rightarrow$$

$$\Rightarrow \frac{U_o}{U_{sig}} = \overset{1}{\cancel{\alpha}} \cdot \frac{R_C // R_L}{R_{sig} + r_e} = \frac{\frac{10 \cdot 10^3 \cdot 10 \cdot 10^3}{10 \cdot 10^3 + 10 \cdot 10^3}}{50 + 50} \Rightarrow$$

$$\Rightarrow \boxed{\frac{U_o}{U_{sig}} = 50}$$

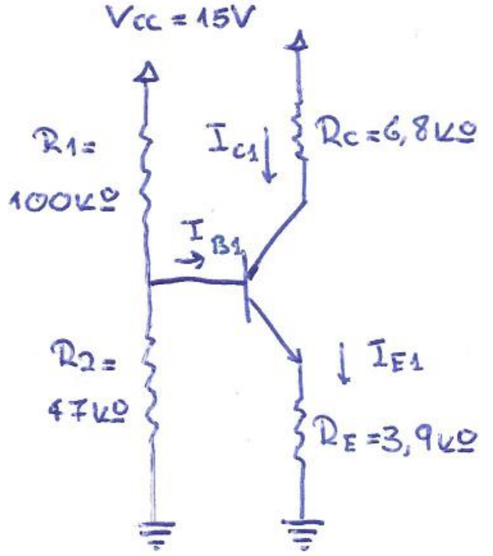
## Άσκηση 7)

Δίνεται το σχήμα Π7.130 από Sedra Smith

α)

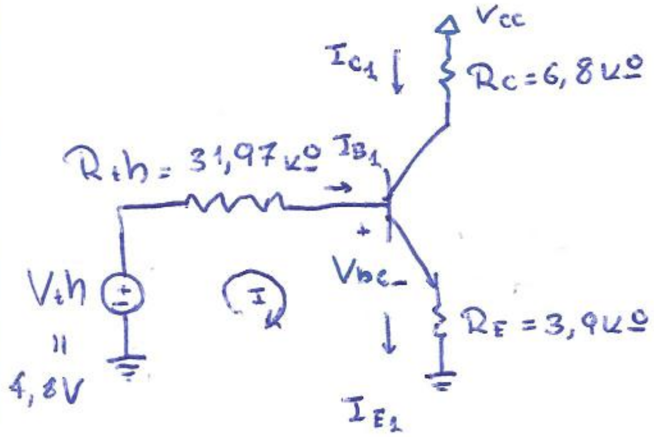
## DC ανάλυση

**Στάδιο 1**




$$V_{th} = V_{CC} \cdot \frac{R_2}{R_1 + R_2} = 15V \cdot \frac{47k\Omega}{100k\Omega + 47k\Omega} = 4,8V$$

$$R_{th} = R_1 \| R_2 = 31,97k\Omega$$




N.T.K (I): $-V_{th} + I_{B1} R_{th} + V_{be} + I_{E1} R_E = 0$

και $I_{E1} = (\beta+1) I_{B1}$

Άρα $-V_{th} + I_{B1} R_{th} + V_{be} + (\beta+1) I_{B1} \cdot R_E = 0$

$\Rightarrow -4,8V + I_{B1} \cdot 31,97k\Omega + 0,7V + (100+1) \cdot I_{B1} \cdot 3,9k\Omega = 0$

$\hookrightarrow I_{B1} = 9,63\ \mu A$

$I_{C1} = \beta I_{B1} = 100 \cdot 9,63\ \mu A = \boxed{0,963mA}$

$V_{C1} = 15V - 6,8k\Omega \cdot 0,963mA = \boxed{8,45V}$

Το transistor του σταδίου 2 είναι πανομοιότυπο με αυτό του σταδίου 1 και έτσι ισχύει ότι:

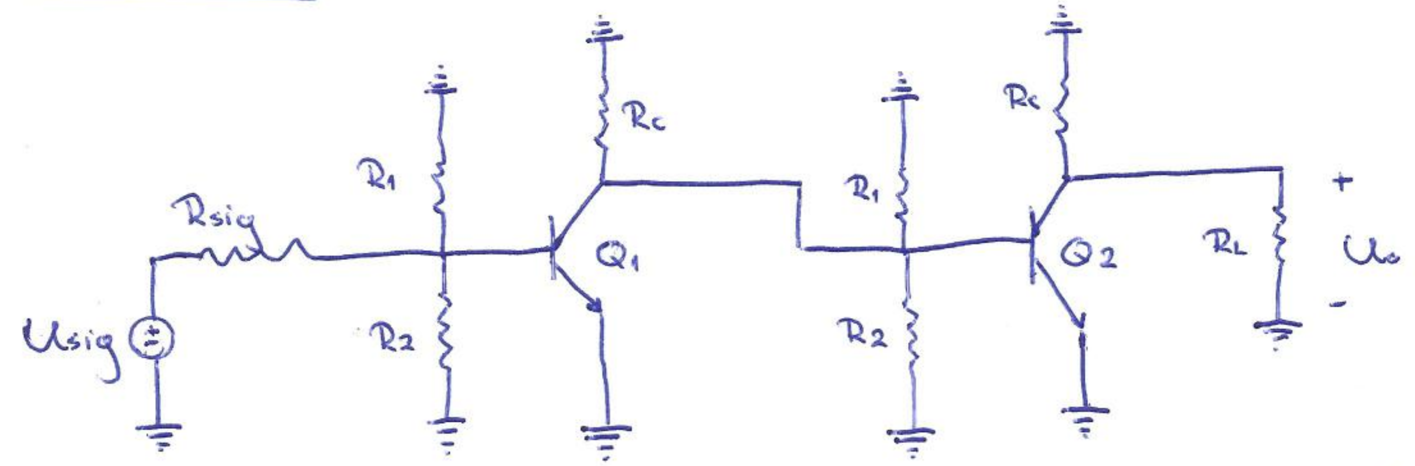
$$\boxed{\begin{aligned} I_{C2} &= I_{C1} = 0,963mA \\ V_{C2} &= V_{C1} = 8,45V \end{aligned}}$$

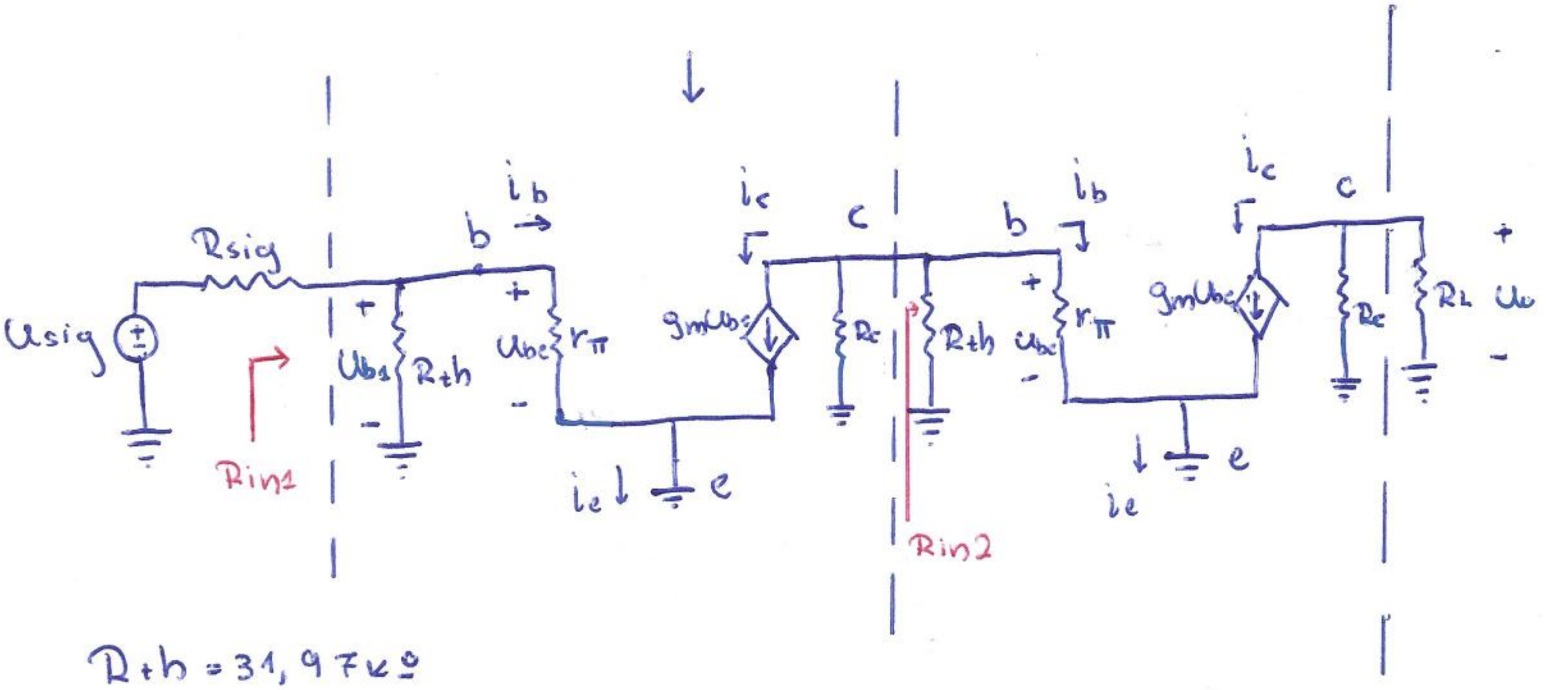
και έχουμε:

- $g_m = \dfrac{I_C}{V_T} = \dfrac{0,963mA}{25mV} = 0,0385$
- $r_\pi = \dfrac{V_T}{I_B} = \dfrac{25mV}{9,63\mu A} = 25,96k\Omega$

B)

## AC ανάλυση



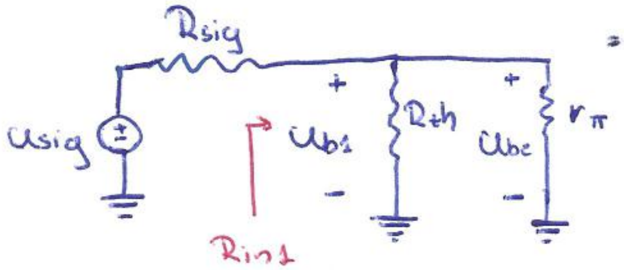

$R_{th} = 31{,}97\,k\Omega$

$r_\pi = 25{,}96\,k\Omega$

$g_m = 0{,}0385$

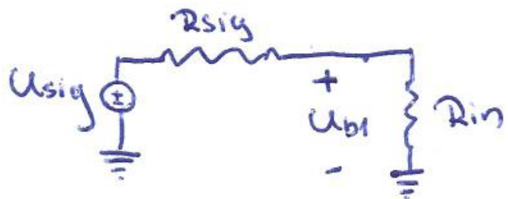
$R_c = 6{,}8\,k\Omega$

γ) $R_{sig} = 5\,k\Omega$




$$R_{in_1} = R_{th} || r_\pi = \frac{31{,}97k\Omega \cdot 25{,}96k\Omega}{31{,}97k\Omega + 25{,}96k\Omega} =$$

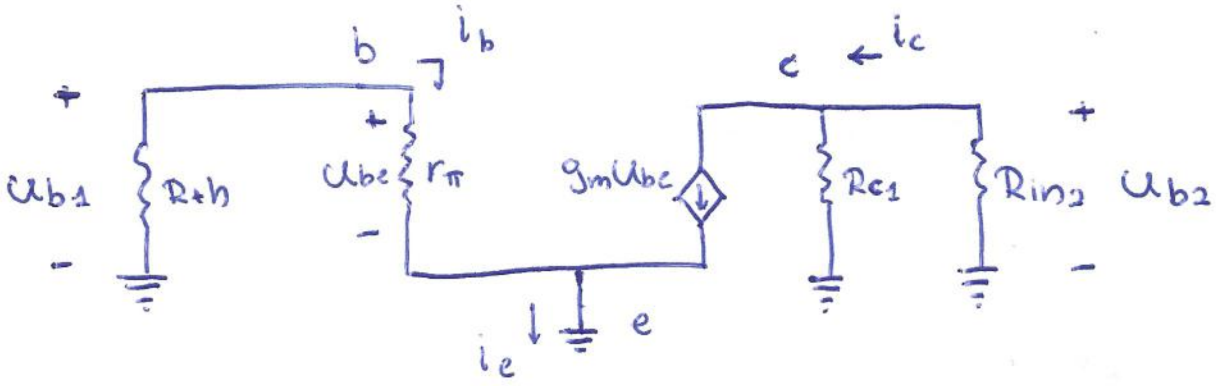
$$= 14{,}33k\Omega \Rightarrow \boxed{R_{in_1} = 14{,}33k\Omega}$$




$$u_{b1} = u_{sig} \cdot \frac{R_{in_1}}{R_{in_1} + R_{sig}} \Rightarrow \frac{u_{b1}}{u_{sig}} = \frac{14{,}33k\Omega}{14{,}33k\Omega + 5k\Omega} \Rightarrow$$

$$\Rightarrow \boxed{\frac{u_{b1}}{u_{sig}} = 0{,}74}$$

δ) $R_{in2} = R_{th} \| r_\pi = R_{in1} = \boxed{14{,}33\,k\Omega}$




$$i_c = g_m u_{be}$$

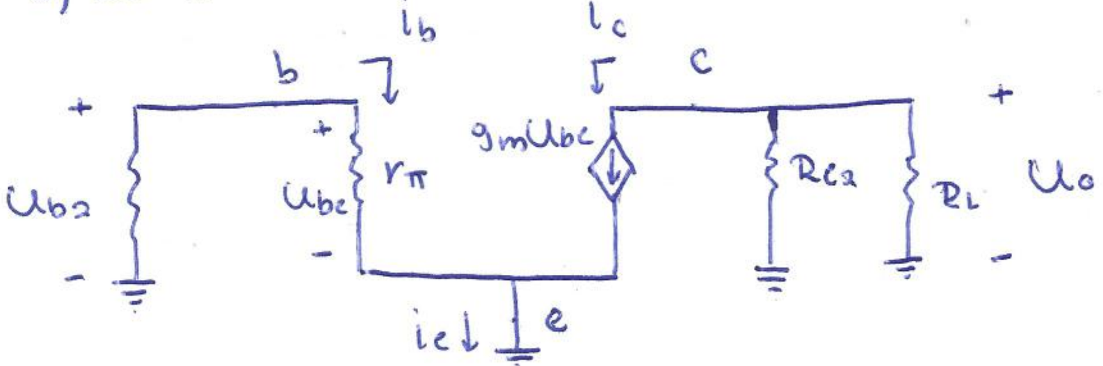
$$u_{b2} = -i_c (R_{in2} \| R_C) = -g_m u_{be} (R_{in2} \| R_C)$$

$$u_{be} = u_{b1} \Rightarrow u_{b2} = -g_m u_{b1} (R_{in2} \| R_C)$$

$$\Rightarrow \frac{u_{b2}}{u_{b1}} = -g_m (R_{in2} \| R_C) =$$

$$= -0{,}0385 \cdot \frac{14{,}33\,k\Omega \cdot 6{,}8\,k\Omega}{14{,}33\,k\Omega + 6{,}8\,k\Omega} = \boxed{-177{,}55}$$

ε) $R_L = 2\,k\Omega$




$$\frac{u_o}{u_{b2}} = -g_m (R_{C2} \| R_L) = -0{,}0385 \cdot \frac{6{,}8\,k\Omega \cdot 2\,k\Omega}{6{,}8\,k\Omega + 2\,k\Omega} = \boxed{-59{,}5}$$

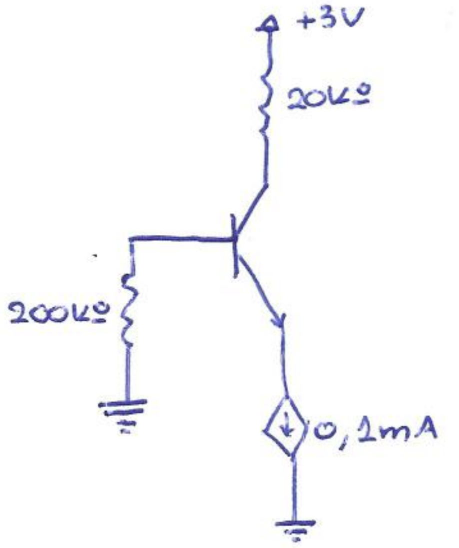
$$\frac{u_o}{u_{sig}} = \frac{u_{b1}}{u_{sig}} \cdot \frac{u_{b2}}{u_{b1}} \cdot \frac{u_o}{u_{b2}} = 0,77 \cdot (-177,55)\cdot(-59,5) \Rightarrow$$

$$\Rightarrow \boxed{\frac{u_o}{u_{sig}} = 7831,1}$$

## Άσκηση 8)

Δίνεται το σχήμα Π7.131 από Sedra Smith

DC ανάλυση




$\beta = 100$

$I_E = 0,1mA$

$I_C = a \cdot I_E = \frac{100}{100+1} \cdot 0,1mA = 0,099mA$

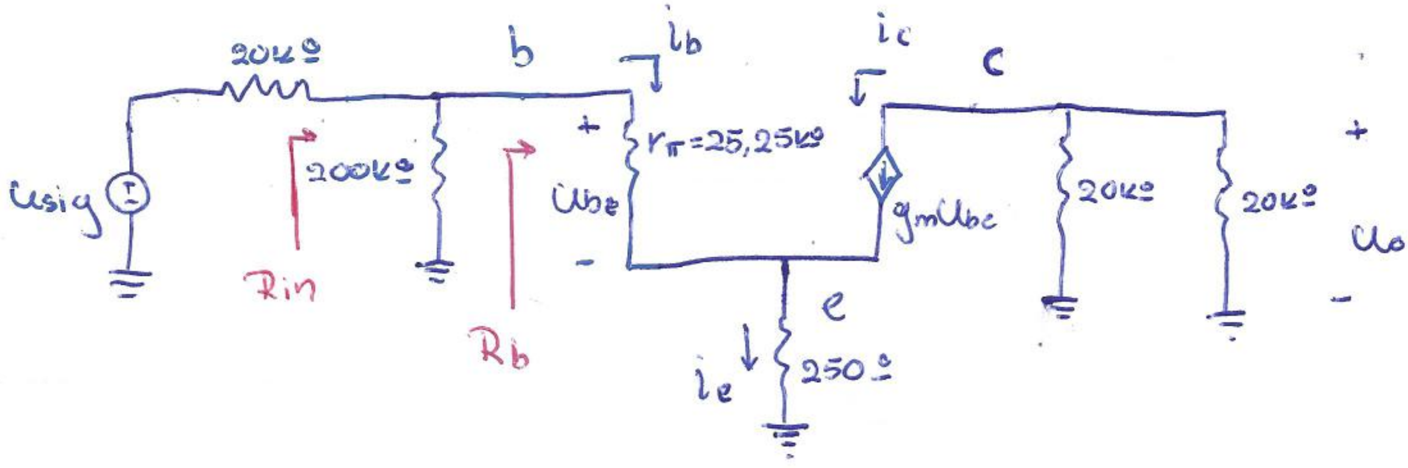
$V_C = 3 - 20k\Omega \cdot 0,099mA = 1,02V$

$g_m = \frac{I_C}{V_T} = \frac{0,099mA}{25mV} = 0,00396$

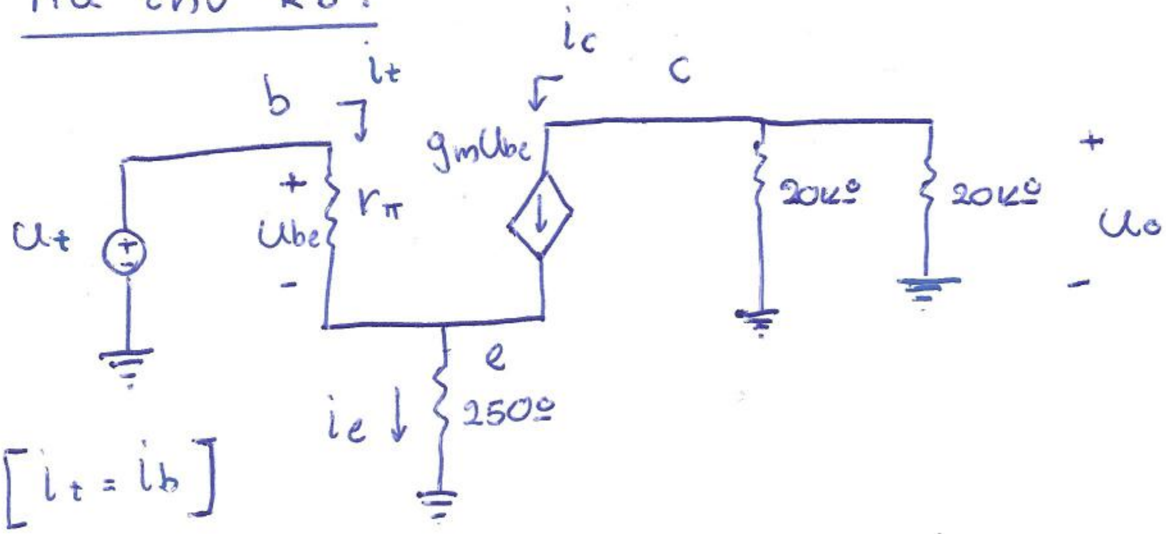
$r_e = \frac{V_T}{I_E} = \frac{25mV}{0,1mA} = 250\Omega$

$r_\pi = \frac{\beta}{g_m} = \frac{100}{0,00396} = 25250\Omega = 25,25k\Omega$

AC ανάλυση



## Για την Rb:




$[i_t = i_b]$

$$i_t + i_c = i_e \Rightarrow i_e = i_b + B i_b = (B+1) i_b$$

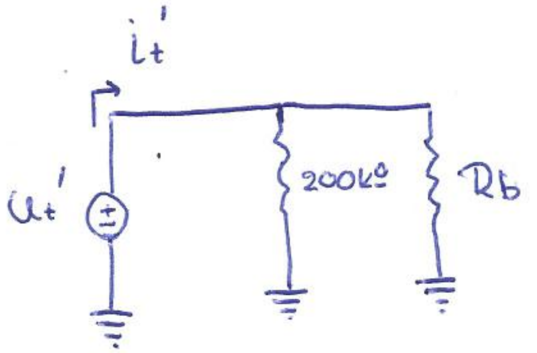
$$u_t = u_{be} + i_e \cdot 250\Omega = i_b \cdot r_\pi + i_e \cdot 250\Omega =$$

$$= i_b \cdot r_\pi + (B+1) \cdot i_b \cdot 250\Omega = i_b \left( r_\pi + (B+1) 250\Omega \right) =$$

$$= i_t \cdot [r_\pi + (B+1) \cdot 250\Omega] \Rightarrow$$

$$\frac{u_t}{i_t} = r_\pi + (B+1) \cdot 250\Omega = R_b \Rightarrow$$

$$\Rightarrow R_b = 25{,}25\,k\Omega + (100+1) \cdot 250\Omega = 50500\Omega$$

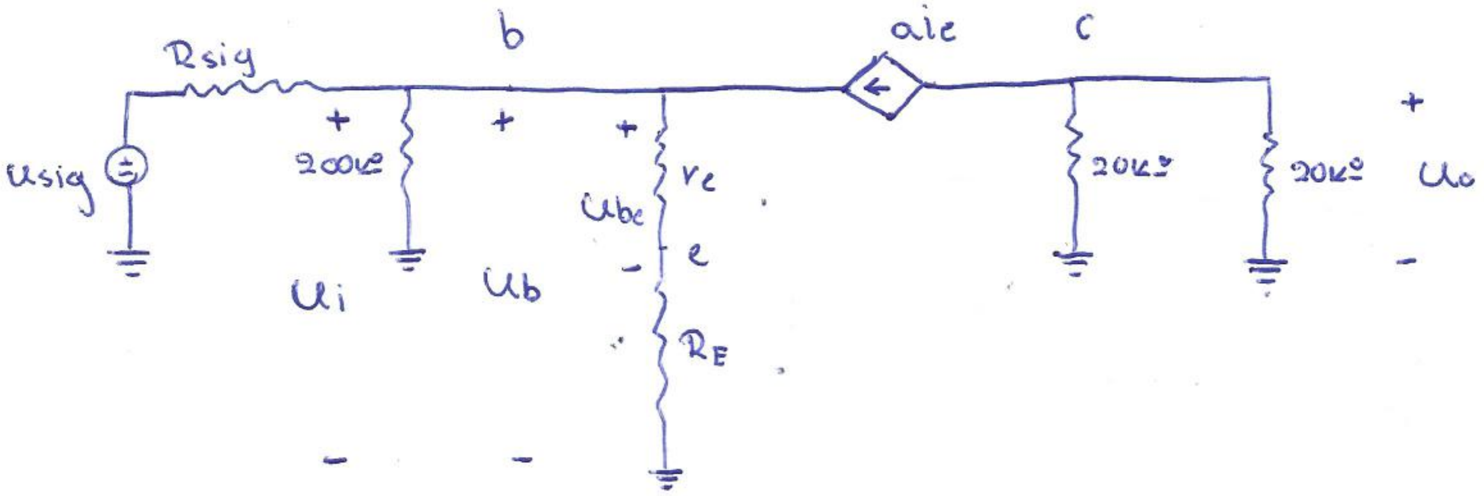



$$\frac{u_t'}{i_t'} = R_{in} = 200\,k\Omega // R_b =$$

$$= \frac{200 \cdot 10^3 \cdot 50500}{200 \cdot 10^3 + 50500} =$$

$$= 40{,}32\,k\Omega$$

## Για το κέρδος $u_o/u_{sig}$:




$$\frac{u_o}{u_b} = -\beta \cdot \frac{R_c \parallel R_L}{R_{sig} + (\beta+1)(r_e + R_e)} =$$

$$= -100 \cdot \frac{\frac{20\cdot10^3 \cdot 20\cdot10^3}{20\cdot10^3 + 20\cdot10^3}}{20\cdot10^3 + 101\,(250+250)} = -14{,}18$$

$$\frac{u_i}{u_{sig}} = \frac{R_{in}}{R_{in} + R_{sig}} \quad (1)$$

$$R_{in} = (\beta+1)(r_e + R_e) = 101\cdot(500) = 50{,}5\ k\Omega$$

$$\xrightarrow{(1)} \frac{u_i}{u_{sig}} = \frac{50{,}5\cdot10^3}{20\cdot10^3 + 50{,}5\cdot10^3} = 0{,}716$$

$$\frac{u_o}{u_{sig}} = 0{,}716\cdot(-14{,}18) = \boxed{-10{,}16}$$

$$u_{i\,max} = 0{,}716\cdot 5mV = \boxed{3{,}58mV}$$

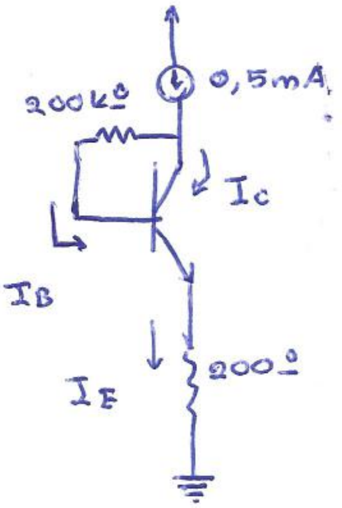
$$u_{o\,max} = 3{,}58mV\cdot(-14{,}18) = \boxed{-50{,}8mV}$$

Άσκηση 9)

Δίνεται το σχήμα Π.7.132 από sedra Smith.

DC ανάλυση

α)




$I_C + I_B = 0,5mA \Rightarrow \beta I_B + I_B = 0,5mA$

$\Rightarrow I_B(\beta+1) = 0,5mA \Rightarrow$

$\Rightarrow I_B = \dfrac{0,5mA}{101} = 0,00495mA = 4,95\mu A$

$I_C = \beta I_B = 100 \cdot 4,95\mu A = 0,495mA$

$I_E = (\beta+1) I_B = I_C + I_B = 0,5mA$

$V_E = 200\Omega \cdot 0,5mA = 0,1V$

$V_B = 0,1V + 0,7V = 0,8V$

$V_C - V_B = 200k\Omega \cdot I_B \Rightarrow V_C = 200k\Omega\, I_B + V_B$

$= 200k\Omega \cdot 4,95\mu A + 0,8V = 1,79V$

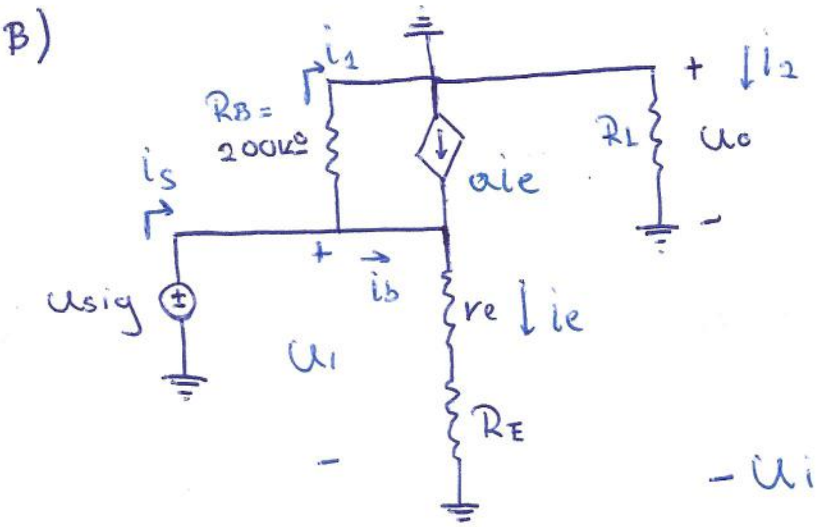
Άρα $\boxed{I_C = 0,495mA \text{ και } V_C = 1,79V}$

$g_m = \dfrac{I_C}{V_T} = \dfrac{0,495mA}{25mV} =$

$= 0,0198$

$r_e = \dfrac{V_T}{I_E} = \dfrac{25mV}{0,5mA} = 50\Omega$

β)




$u_o = i_2 R_L \; (1)$

$i_1 = \alpha i_e + i_2 \; (2)$

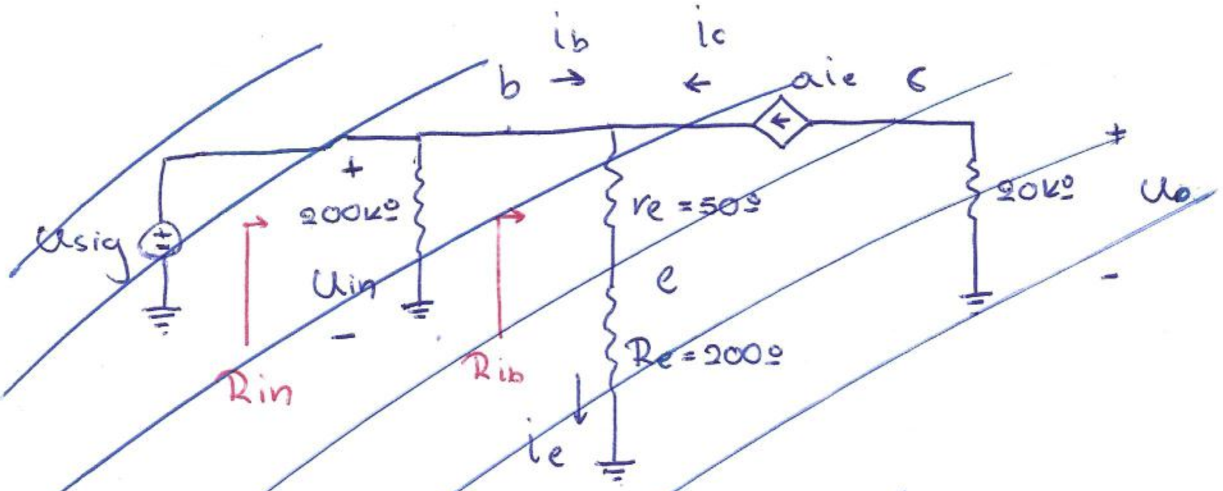
$i_e = \dfrac{u_i}{r_e + R_e} \; (3)$

$-u_i + R_B i_1 + u_o = 0 \Rightarrow$

$u_i = R_B i_1 + u_o \Rightarrow$

$\Rightarrow u_o = u_i - R_B i_1 \overset{(2)}{=} u_i - R_B(\alpha i_e + i_2) \Rightarrow$

$\Rightarrow u_o = u_i - R_B\left(\alpha \cdot \dfrac{u_i}{R_e + r_e} + \dfrac{u_o}{R_L}\right) R_B \Rightarrow$




$$R_{in} = 200k\Omega \,//\, R_{ib}$$

$$R_{ib} = (r_e + R_e)(\beta + 1)$$

$$\left.\begin{aligned} U_o &= -\alpha i_e \cdot 20k\Omega \\ i_e &= \frac{U_i}{r_e + R_e} \end{aligned}\right\} U_o = -\alpha \cdot \frac{U_i}{r_e + R_e} \cdot 20k\Omega \Rightarrow \frac{U_o}{U_i} = -\alpha \frac{20k\Omega}{r_e + R_e}$$

Εφόσον δεν έχουμε αντίσταση Rsig:

$$U_{in} = U_{sig} \Rightarrow \frac{U_o}{U_i} = \frac{U_o}{U_{sig}}$$

$$\Rightarrow U_o = U_i - \frac{\alpha R_B U_i}{R_e + r_e} - \frac{U_o}{R_L} \cdot R_B \Rightarrow$$

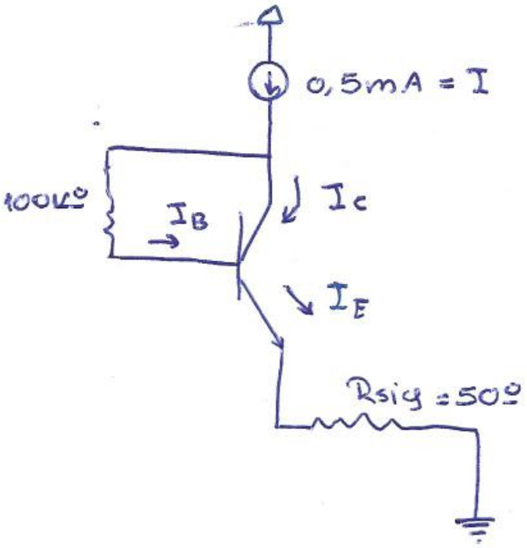
$$\Rightarrow U_o \left(1 + \frac{R_B}{R_L}\right) = U_i \left(1 - \frac{\alpha R_B}{R_e + r_e}\right) \Rightarrow$$

$$\Rightarrow \frac{U_o}{U_i} = \frac{1 + \frac{R_B}{R_L}}{1 - \alpha \frac{R_B}{R_e + r_e}} \Rightarrow \boxed{\frac{U_o}{U_i} = -71{,}91}$$

## Άσκηση 10)

Δίνεται το σχήμα Π7.133 από Sedra Smith.

### DC ανάλυση



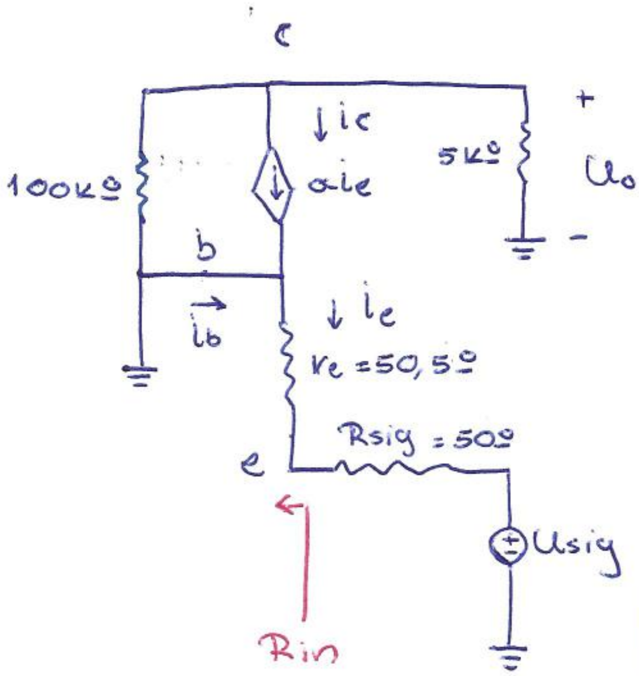

$$I = I_C + I_B = I_E = 0.5mA$$

$$\beta = 100,$$

$$I_C = \alpha \cdot I_E = \frac{100}{100+1} \cdot 0,5mA = 0,495mA$$

$$r_e = \frac{V_T}{I_E} = \frac{25mV}{0,495mA} = 50,5\Omega$$

### AC ανάλυση




$$R_{in} = r_e = 50,5\Omega$$

$$i_c = \alpha \cdot i_e$$

$$u_o = \alpha \cdot i_e (100k\Omega \parallel 5k\Omega) \quad (1)$$

$$i_e = -\frac{u_{sig}}{R_{in} + R_{sig}}$$

$$\xrightarrow{(1)(2)} u_o = \alpha \cdot -\frac{u_{sig}}{R_{in}+R_{sig}} \cdot (100k\Omega // 5k\Omega)$$

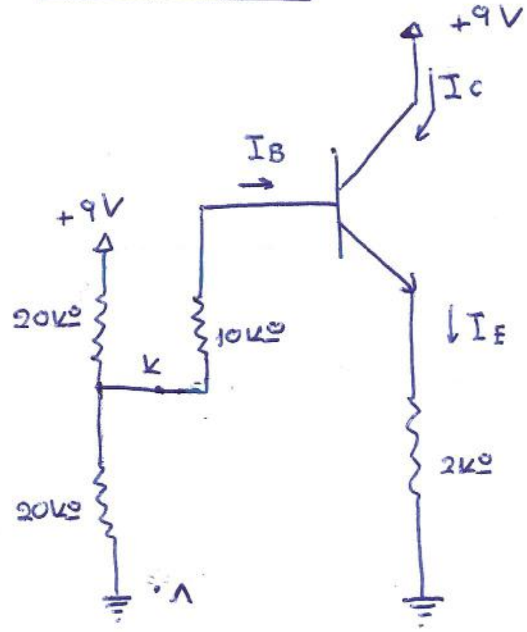
$$\Rightarrow \frac{u_o}{u_{sig}} = \frac{\alpha \cdot (100k\Omega \parallel 5k\Omega)}{R_{in}+R_{sig}} \Rightarrow$$

$$\Rightarrow \frac{u_o}{u_{sig}} = \frac{\frac{100}{101} \cdot \frac{100\cdot 10^3 \cdot 5\cdot 10^3}{100\cdot 10^3 + 5\cdot 10^3}}{50,5 + 50} = \boxed{46,91}$$

Άσκηση 11)

Δίνεται το σχήμα Π7.136 από Sedra Smith.

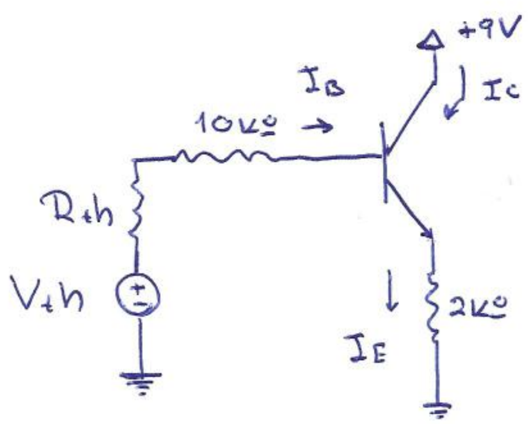
DC ανάλυση




Thevenin αριστερά των ακροδεκτών κ, λ:

$$V_{th} = 9V \cdot \frac{20k\Omega}{20k\Omega + 20k\Omega} = 4{,}5V$$

$$R_{th} = (20k\Omega) \| (20k\Omega) = 10k\Omega$$




$$V_{th} - V_B = (R_{th} + 10k\Omega) \cdot I_B \Rightarrow 4{,}5 - V_B = (10k\Omega + 10k\Omega) \cdot I_B \ (1)$$

$$V_E = V_B - 0{,}7V = 2k\Omega \cdot I_E \Rightarrow$$

$$\Rightarrow V_B - 0{,}7V = 2k\Omega \cdot (1 + \beta) \cdot I_B \Rightarrow$$

$$\Rightarrow V_B - 0{,}7V = 2k\Omega \cdot (1 + 100) \cdot I_B \ (2)$$

$$\xrightarrow{(1)(2)} V_B = 4{,}16V \text{ κ' } I_B = 17{,}1\mu A$$

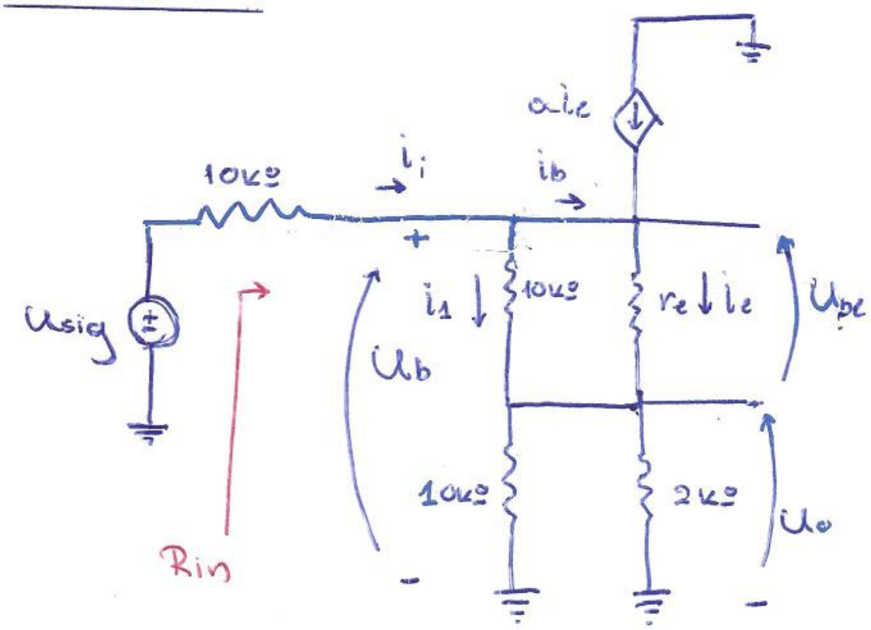
$$I_C = \beta \cdot I_B = 100 \cdot 17{,}1\mu A = 1{,}71mA$$

$$I_E = (\beta + 1) I_B = 101 \cdot 17{,}1\mu A = 1{,}73mA$$

και έχουμε:

- $g_m = \dfrac{I_C}{V_T} = \dfrac{1{,}71mA}{25mV} = 0{,}0684S$
- $r_\pi = \dfrac{V_T}{I_B} = \dfrac{25mV}{17{,}1\mu A} = 1{,}46k\Omega$
- $r_e = \dfrac{V_T}{I_E} = \dfrac{25mV}{1{,}73mA} = 14{,}48\Omega$

B/ AC ανάλυση




$$U_{be} = r_e i_e = 10k\Omega \cdot i_1 \Rightarrow$$

$$\Rightarrow i_1 = \frac{r_e i_e}{10k\Omega}$$

$$U_o = (i_1 + i_e)(10k\Omega // 2k\Omega) = \left(\frac{r_e i_e}{10k\Omega} + i_e\right)(10k\Omega // 2k\Omega)$$

$$R_{in} = \frac{U_b}{i_i} \; (1), \quad U_b = U_o + U_{be} = \left(\frac{r_e i_e}{10k\Omega} + i_e\right)(10k\Omega // 2k\Omega) + r_e i_e$$

$$i_i = i_b + i_1 = \frac{i_e}{\beta + 1} + \frac{r_e i_e}{10k\Omega}$$

$$\xrightarrow{(1)} R_{in} = \frac{\left(\frac{r_e \cancel{i_e}}{10k\Omega} + \cancel{i_e}\right)(10k\Omega // 2k\Omega) + r_e \cancel{i_e}}{\frac{\cancel{i_e}}{\beta + 1} + \frac{r_e \cancel{i_e}}{10k\Omega}} \Rightarrow$$

$$\Rightarrow R_{in} = \frac{\left(\frac{r_e}{10k\Omega} + 1\right)(10k\Omega // 2k\Omega) + r_e}{\frac{1}{\beta + 1} + \frac{r_e}{10k\Omega}} =$$

$$= \frac{\left(\frac{14,48}{10 \cdot 10^3} + 1\right)\left(\frac{10 \cdot 10^3 \cdot 2 \cdot 10^3}{10 \cdot 10^3 + 2 \cdot 10^3}\right) + 14,48}{\frac{1}{101} + \frac{14,48}{10 \cdot 10^3}} = 148344,5\Omega \Rightarrow$$

$$\Rightarrow \boxed{R_{in} = 148,3\ k\Omega}$$

$$\frac{u_b}{u_{sig}} = \frac{R_{in}}{R_{in} + R_{sig}} = \frac{148,3\,k\Omega}{148,3\,k\Omega + 10\,k\Omega} = 0,937$$

$$\frac{u_o}{u_b} = \frac{\left(\frac{r_e i_e}{10\,k\Omega} + i_e\right)\left(10\,k\Omega \parallel 2\,k\Omega\right)}{\left(\frac{r_e i_e}{10\,k\Omega} + i_e\right)\left(10\,k\Omega \parallel 2\,k\Omega\right) + r_e i_e} =$$

$$= \frac{i_e\left(\frac{r_e}{10\,k\Omega} + 1\right)\left(10\,k\Omega \parallel 2\,k\Omega\right)}{i_e\left(\frac{r_e}{10\,k\Omega} + 1\right)\left(10\,k\Omega \parallel 2\,k\Omega\right) + r_e i_e} =$$

$$= \frac{1,73 \cdot 10^{-3}\left(\frac{14,48}{10 \cdot 10^3} + 1\right)\left(\frac{10 \cdot 2 \cdot 10^6}{10^4 + 2 \cdot 10^3}\right)}{1,73 \cdot 10^{-3}\left(\frac{10 \cdot 2 \cdot 10^6}{10^4 + 2 \cdot 10^3}\right) + 14,48 \cdot 1,73 \cdot 10^{-3}} =$$

$$= 0,991$$

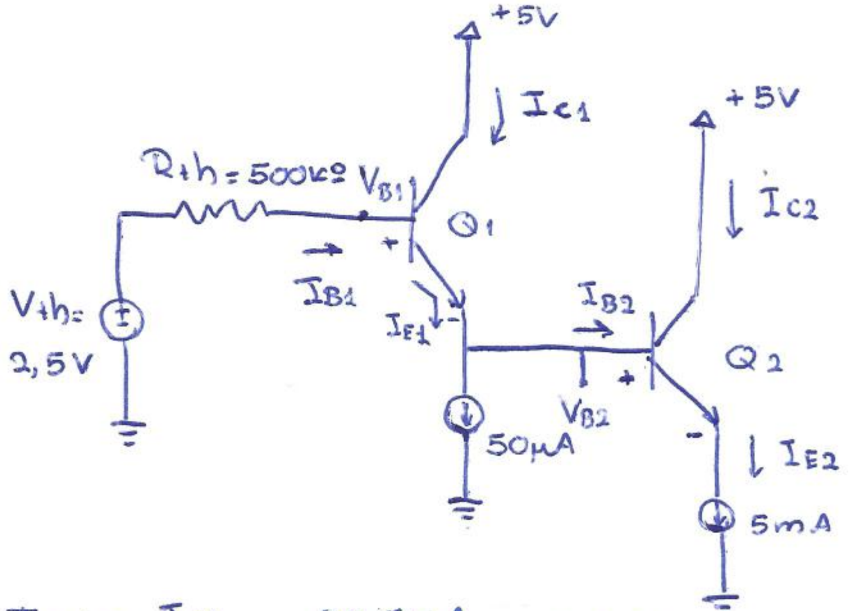
$$\frac{u_o}{u_{sig}} = 0,937 \cdot 0,991 \Rightarrow \boxed{G_v = 0,93\ V/V}$$

## 'Ασκηση 12)

Δίνεται το σχήμα Π7.137 από Sedra Smith

α) DC ανάλυση.

$$V_{th} = 5 \cdot \frac{1M\Omega}{1M\Omega + 1M\Omega} = 2,5V \quad , \quad R_{th} = 1M\Omega // 1M\Omega = 500k\Omega$$




$B_1 = 50$ κ' $B_2 = 100$

$\boxed{I_{E2} = 5mA}$

$I_{E2} = (B_2+1) I_{B2} \Rightarrow$

$\Rightarrow I_{B2} = \frac{5mA}{101} = 0,0495mA$

$-V_{B2} + 0,7 = 0 \Rightarrow \boxed{V_{B2} = 0,7V}$

$I_{E1} = I_{B2} + 50\mu A =$

$= 49,5\mu A + 50\mu A =$

$= \boxed{99,5\mu A}$

$$I_{B1} = \frac{I_{E1}}{B_1+1} = \frac{99,5\mu A}{51} = 1,951\mu A$$

$$-V_{th} + I_{B1} R_{th} + V_{B1} = 0 \Rightarrow V_{B1} = 2,5 - (1,951\mu A \cdot 500k\Omega) \Rightarrow \boxed{V_{B1} = 1,53} V$$

$$V_{B2} = 1,53 - 0,7 = \boxed{0,83V}$$

$$I_{C2} = \alpha I_{E2} = \frac{100}{101} \cdot 5mA = 4,95mA$$

$$I_{C1} = \alpha I_{E1} = \frac{100}{101} \cdot 99,5\mu A = 98,5\mu A = 0,0985mA$$

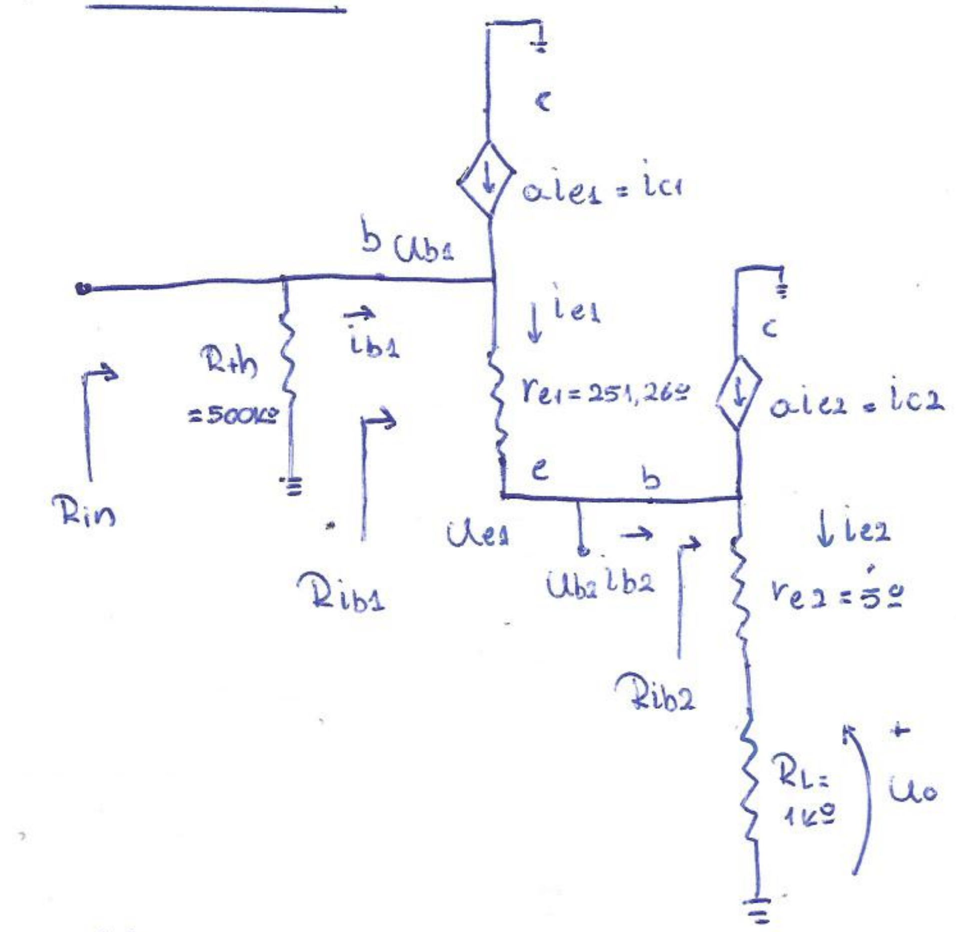
$$g_{m1} = \frac{I_{C1}}{V_T} = \frac{0,0985mA}{0,25mV} = 0,394\,S$$

$$r_{e1} = \frac{V_T}{I_{E1}} = \frac{25mV}{0,0995mA} = 251,26\Omega$$

$$g_{m2} = \frac{I_{C2}}{V_T} = \frac{4,95mA}{0,25mA} = 19,8\,S$$

$$r_{e2} = \frac{V_T}{I_{E2}} = \frac{25mV}{5mA} = 5\Omega$$

B) AC ανάλυση




$$\upsilon_o = \upsilon_{b2} \cdot \frac{R_L}{R_L + r_{e2}} \Rightarrow \frac{\upsilon_o}{\upsilon_{b2}} = \frac{10^3}{10^3+5} = \boxed{0,995}$$

$$R_{ib2} = (R_L + r_{e2})(B_2+1) = (10^3+5)(101) = 101,51k\Omega$$

$$\upsilon_{b1} = \upsilon_{e1} \cdot \frac{R_{ib2}}{R_{ib2} + r_{e1}} \Rightarrow \frac{\upsilon_{b1}}{\upsilon_{e1}} = \frac{101,51k\Omega}{101,51k\Omega + 251,26\Omega} = \boxed{0,998}$$

$$R_{ib1} = (R_{ib2} + r_{e1})(B_1+1)$$

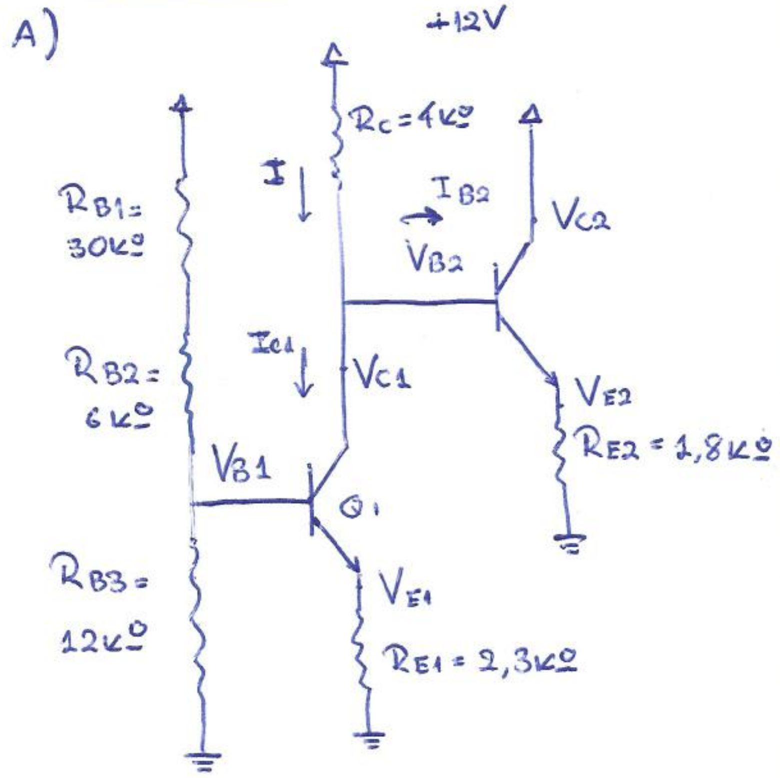
$$R_{in} = R_{th} // R_{ib1} = \frac{R_{th}(R_{ib2}+r_{e1})(B_1+1)}{R_{th} + (R_{ib2}+r_{e1})(B_1+1)} =$$

$$= \frac{500k\Omega\,(101,51k\Omega + 251,26\Omega)\ 51}{500 \cdot 10^3 + (101,51k\Omega + 251,26) \cdot 51} = \boxed{456,06k\Omega}$$

Άσκηση 13)

DC ανάλυση

A)




$\beta = 200$

$V_T = 25mV$

$V_{BE} = 0,7V$

$R_{th} = (R_{B1} + R_{B2}) // R_{B3} =$

$= \frac{(30k\Omega + 6k\Omega) \cdot 12k\Omega}{30k\Omega + 6k\Omega + 12k\Omega} = 9k\Omega$

$V_{th} = 12 \cdot \frac{12k\Omega}{30k\Omega + 6k\Omega + 12k\Omega} =$

$= 3 \ V$

$V_{B1} = V_{th} - I_{B1} \cdot R_{th} = 3 - I_{B1} \cdot 9k\Omega \ (1)$

$V_{E1} = I_{E1} \cdot R_{E1} = (\beta + 1) I_{B1} \cdot 2,3k\Omega \ (2)$

$V_{B1} = V_{E1} + 0,7 \ (3)$

$\xrightarrow{(2)(3)} \left. \begin{array}{l} V_{B1} - 0,7 = (\beta + 1) \cdot I_{B1} \cdot 2,3k\Omega \\ V_{B1} = 3 - I_{B1} \cdot 9k\Omega \end{array} \right\} \begin{array}{l} \boxed{V_{B1} = 2,96 \ V} \\ I_{B1} = 4,9 \ \mu A \end{array}$

$\xrightarrow{(3)} \boxed{V_{E1} = 3 - 0,7 = 2,3 \ V}$

$\xrightarrow{(2)} I_{E1} = \frac{V_{E1}}{R_{E1}} = \frac{2,3}{2,3 \cdot 10^3} = 1 \ mA$

$I_{C1} = \alpha I_{E1} = \frac{200}{201} \cdot 1 \ mA = 0,995 mA$

$\left. \begin{array}{l} 12 - V_{C1} = R_C \cdot I \\ V_{C1} = V_{B2} \end{array} \right\} \left. \begin{array}{l} 12 - V_{B2} = 4k\Omega \cdot I \\ I = I_{C1} + I_{B2} \end{array} \right\} 12 - V_{B2} = 4k\Omega (I_{C1} + I_{B2})$

$\Rightarrow$

$$\Rightarrow 12 - V_{B2} = 4k\Omega\,(0{,}995\,mA + I_{B2}) \quad (4)$$

$$\left.\begin{aligned} &V_{B2} - 0{,}7 = I_{E2} \cdot R_{E2} \Rightarrow V_{B2} - 0{,}7 = I_{E2} \cdot 1{,}8k\Omega \quad (5) \\ &I_{E2} = (\beta+1) I_{B2} \end{aligned}\right\}$$

$$\Rightarrow V_{B2} - 0{,}7 = (\beta+1) I_{B2} \cdot 1{,}8k\Omega \quad (6)$$

$$\xrightarrow{(4)(6)} \left\{\begin{aligned} &12 - V_{B2} = 4k\Omega\,(0{,}995\,mA + I_{B2}) \\ &V_{B2} - 0{,}7 = (200+1) I_{B2} \cdot 1{,}8k\Omega \end{aligned}\right\} \left\{\begin{aligned} &V_{B2} = 7{,}94\,V = V_{C1} \\ &I_{B2} = 20\,\mu A \end{aligned}\right.$$

$$V_{E2} = V_{B2} - 0{,}7V = 7{,}94 - 0{,}7 = 7{,}24V$$

Άρα έχουμε:

| | |
|---|---|
| $V_{B1} = 2{,}96\,V$ | $V_{B2} = 7{,}94\,V$ |
| $V_{E1} = 2{,}3\,V$ | $V_{E2} = 7{,}24\,V$ |
| $V_{C1} = 7{,}94\,V$ | $V_{C2} = 12\,V$ |

$$I_{C2} = \beta I_{B2} = 200 \cdot 20\mu A = 4mA$$

$$I_{E2} = 201 \cdot 20\mu A = 4{,}02mA$$

$$\circ\ g_{m1} = \frac{I_{C1}}{V_T} = \frac{0{,}995mA}{25mV} = 0{,}0398\,S$$

$$\circ\ g_{m2} = \frac{I_{C2}}{V_T} = \frac{4mA}{25mV} = 0{,}16\,S$$

$$\circ\ r_{e1} = \frac{V_T}{I_{E1}} = \frac{25mV}{1mA} = 25\Omega$$

$$\circ\ r_{e2} = \frac{V_T}{I_{E2}} = \frac{25mV}{4{,}02mA} = 6{,}22\Omega$$

Τα ρεύματα:

$I_{B1} = 4{,}9\mu A$

$I_{B2} = 20\mu A$

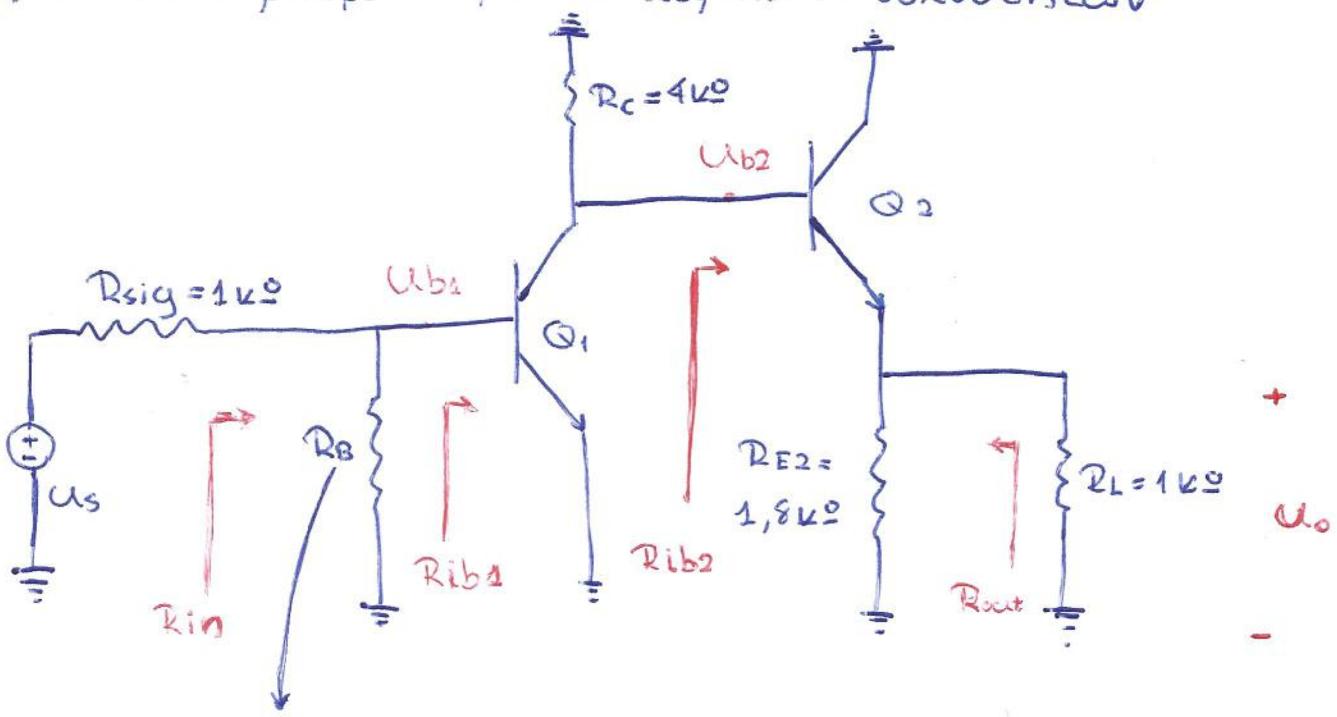
$I_{C1} = 0{,}995mA$

$I_{C2} = 4mA$

$I_{E1} = 1mA$

$I_{E2} = 4{,}02mA$

B) Ανάλυση μικρού σήματος χαμηλών συχνοτήτων




$R_{B2} // R_{B3} = 4k\Omega = R_B$

$Q_2$ : CC συνεπώς έχουμε:

$$\frac{U_o}{U_{b2}} = \frac{R_L // R_{E2}}{(R_L // R_{E2}) + r_{e2}} \quad (1)$$

$$R_{ib2} = (B+1)[r_{e2} + (R_L // R_{E2})]$$

$Q_1$ : CE συνεπώς έχουμε:

$$\frac{U_{b2}}{U_{b1}} = -g_m (R_C // R_{ib2}) =$$

$$= -g_m \left( R_C // (B+1)[r_{e2} + (R_L // R_{E2}] \right) \quad (2)$$

$$\left. \begin{array}{l} R_{in} = R_{ib1} // R_B \\ R_{b1} = (B+1) r_{e1} \end{array} \right\} R_{in} = (B+1) r_{e1} // R_B = \frac{(B+1) r_{e1} \cdot R_B}{(B+1) r_{e1} + R_B} =$$

$$= \frac{(201) \cdot 25 \cdot 4 \cdot 10^3}{201 \cdot 25 + 4 \cdot 10^3} = 2227,15\Omega = 2,23k\Omega$$

$$\frac{U_{b1}}{U_S} = \frac{R_{in}}{R_{in} + R_{sig}} \quad (3)$$

$\xrightarrow{(1)(2)(3)}$ :

$$\frac{U_o}{U_S} = \frac{U_{b1}}{U_S} \cdot \frac{U_{b2}}{U_{b1}} \cdot \frac{U_o}{U_{b2}} = \frac{R_{in}}{R_{in} + R_{sig}} \cdot \left[ -g_m \left( R_C // (B+1)[r_e + (R_L // R_{E2}] \right) \right] \cdot$$

$$\cdot \frac{R_L \| R_{E2}}{(R_L \| R_{E2}) + r_{e2}} \Rightarrow$$

$$\Rightarrow \frac{u_o}{u_s} = \frac{R_{in}}{R_{in}+R_s} \cdot \left[ -g_{m1}\left(R_C \| (\beta+1)\left[ r_{e2} + (R_L \| R_{E2})\right]\right)\right] \cdot \frac{R_L \| R_{E2}}{(R_L \| R_{E2}) + r_{e2}}$$

$R_L \| R_{E2} = 642,86\,\Omega$

$r_{e2} = 6,22\,\Omega$

$r_{e1} = 25\,\Omega$

$R_C = 4\,k\Omega$

$g_{m1} = 0,0398$

$R_{in} = 2,23\,k\Omega$

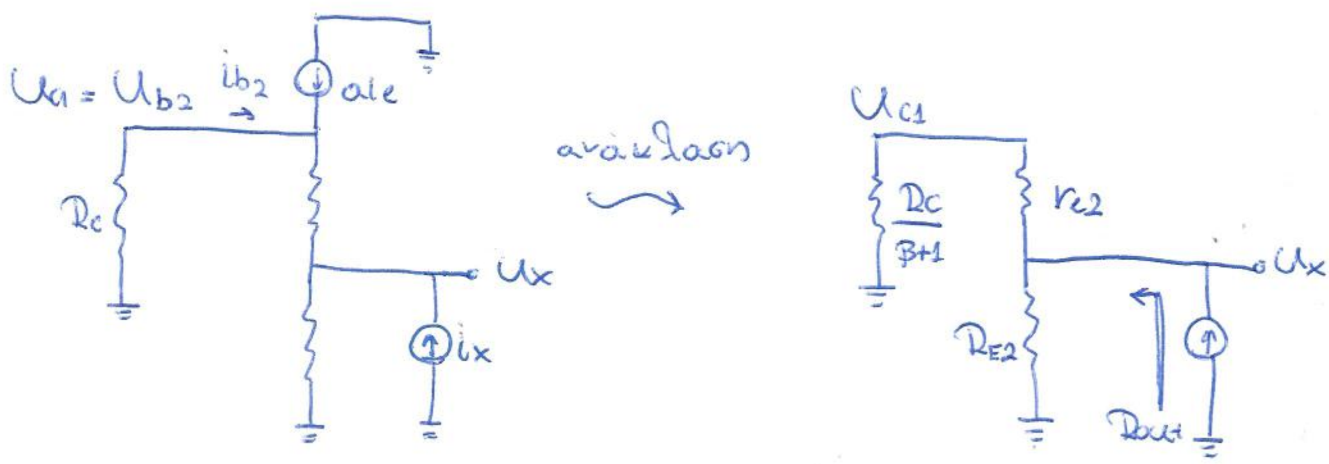
$R_S = 1\,k\Omega$

$$\frac{u_o}{u_s} = \frac{2,23\cdot 10^3}{2,23\cdot 10^3 + 10^3} \cdot \left[ -0,0398 \cdot \frac{4\cdot 10^3 \cdot 201 \cdot (6,22+642,86)}{4\cdot 10^3 + 201\cdot(6,22+642,86)} \right] \cdot \frac{642,86}{642,86+6,22}$$

$$= -105,63\ V/V$$

Γ) $\boxed{R_{in} = 2,23\ k\Omega}$

Δ) Για την αντίσταση εξόδου θα έχουμε το κύκλωμα:



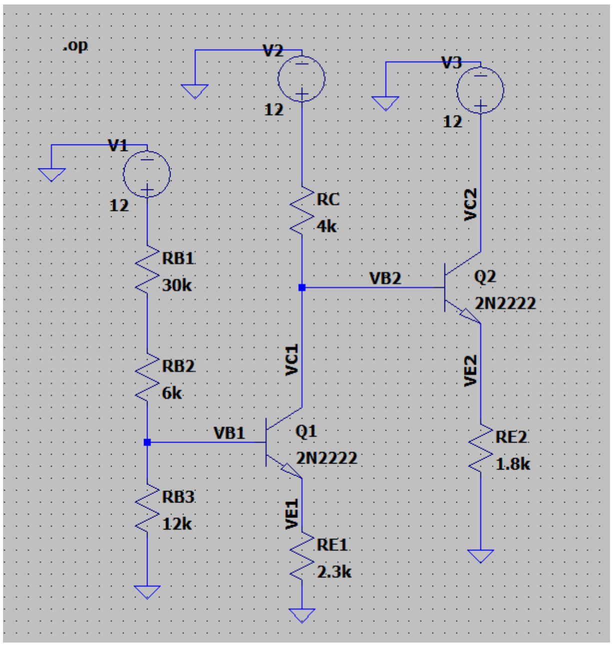
Οπότε : $u_x = i_x \left[ \frac{R_C}{\beta+1} + r_{E2} \right] // R_{E2}$

$$R_{out} = \frac{\cancel{i_x} \left[ \frac{R_C}{\beta+1} + r_{E2} \right] // R_{E2}}{\cancel{i_x}} \Rightarrow R_{out} = \left[ \frac{R_C}{\beta+1} + r_{E2} \right] // R_{E2}$$

$$\Rightarrow \boxed{R_{out} = 25{,}7\,\Omega}$$

Ακολουθούν οι προσομοιώσεις με τη χρήση του ltspice.

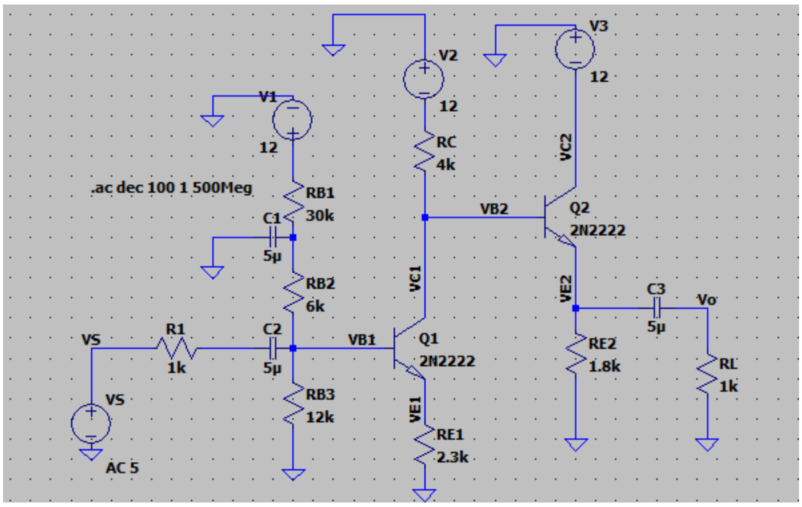
E)

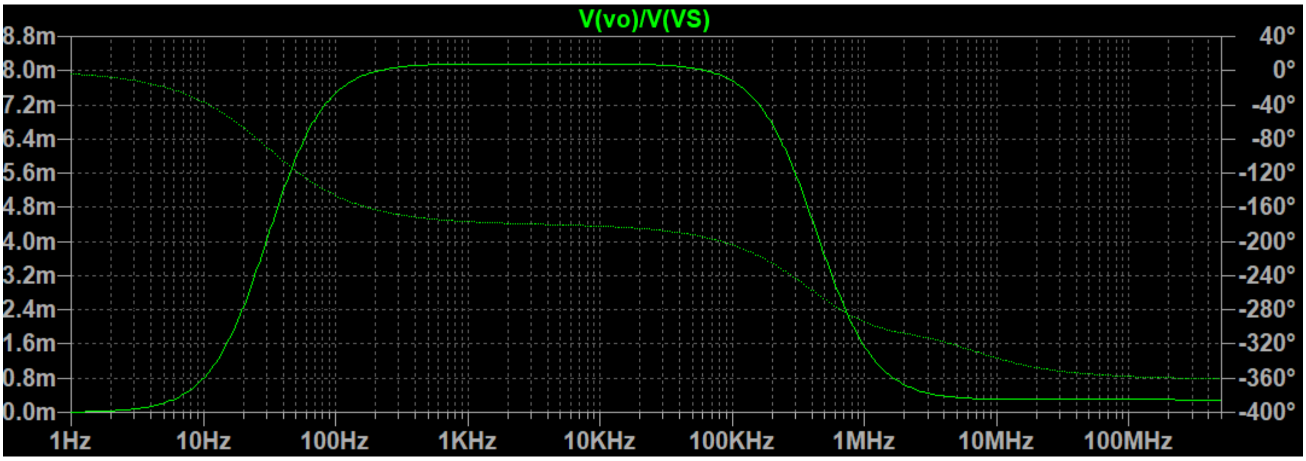



--- Operating Point ---

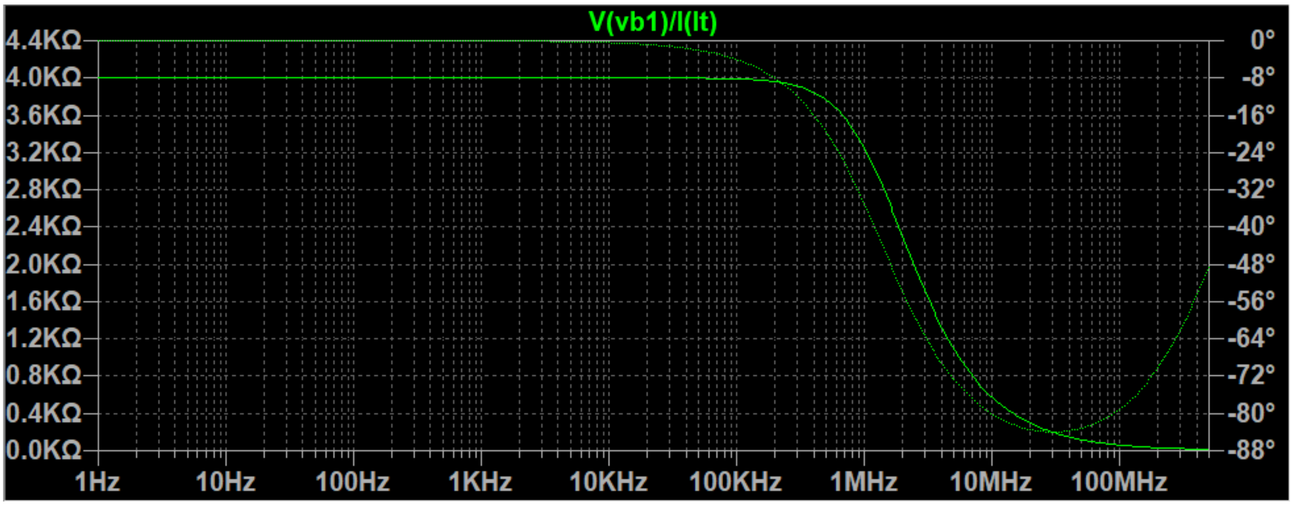
| | | |
|---|---|---|
| V(n002): | 12 | voltage |
| V(n003): | 4.46429 | voltage |
| V(vb1): | 2.95715 | voltage |
| V(vc1): | 7.93588 | voltage |
| V(ve1): | 2.30299 | voltage |
| V(n001): | 12 | voltage |
| V(vc2): | 12 | voltage |
| V(ve2): | 7.24457 | voltage |
| Ic(Q2): | 0.00400527 | device_current |
| Ib(Q2): | 1.94913e-005 | device_current |
| Ie(Q2): | -0.00402476 | device_current |
| Ic(Q1): | 0.000996539 | device_current |
| Ib(Q1): | 4.76135e-006 | device_current |
| Ie(Q1): | -0.0010013 | device_current |
| I(Re2): | 0.00402476 | device_current |
| I(Rc): | 0.00101603 | device_current |
| I(Re1): | 0.0010013 | device_current |
| I(Rb3): | 0.000246429 | device_current |
| I(Rb2): | 0.00025119 | device_current |
| I(Rb1): | 0.00025119 | device_current |
| I(V3): | -0.00400527 | device_current |
| I(V2): | -0.00101603 | device_current |
| I(V1): | -0.00025119 | device_current |

ΣΤ)

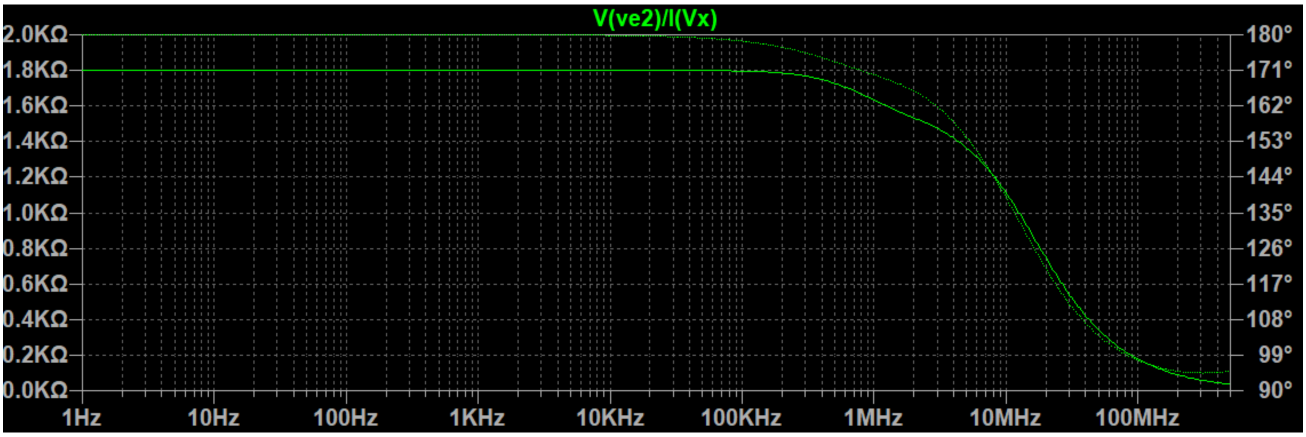


Z)



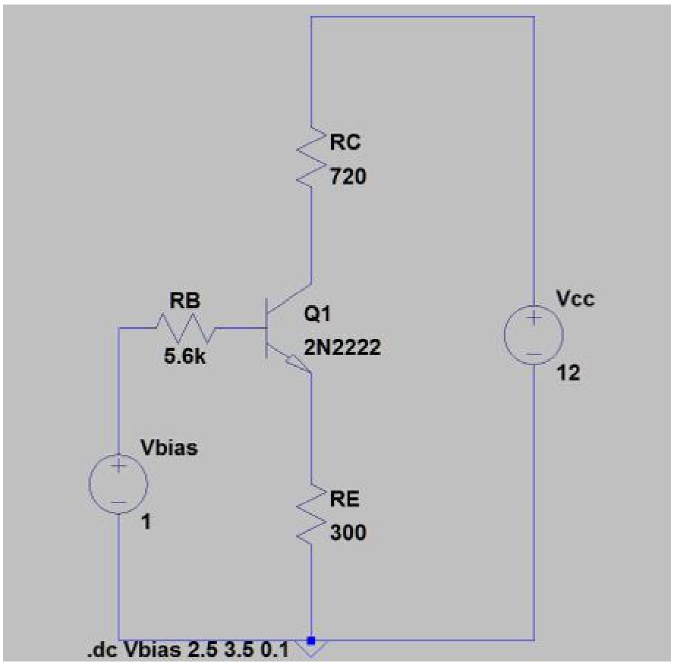

H)



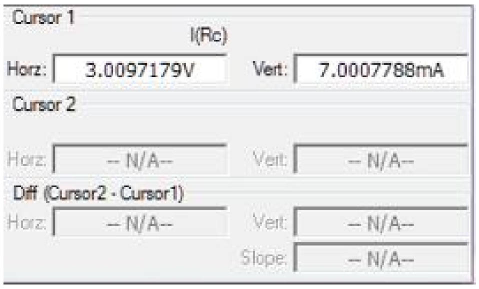

Τα αποτελέσματα συμφωνούν σε καλό βαθμό με τις προσομοιώσεις. Τυχούσες διαφορές οφείλονται πρώτον στο ότι το λογισμικό λαμβάνει υπόψη και το φαινόμενο early και δεύτερον στο ότι οι πυκνωτές δεν παίρνουν την τιμή 0 (πλήρης βραχυκύκλωση) όπως υποθέτουμε στην ανάλυση στο χέρι.

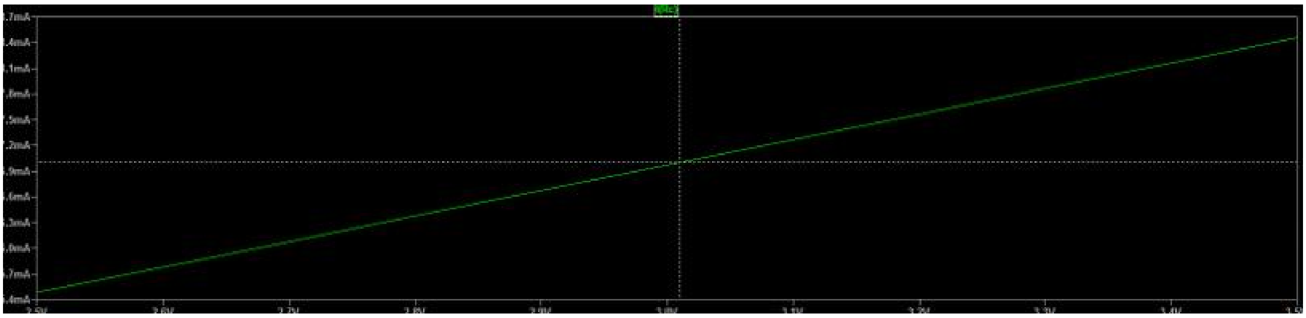
Άσκηση 14)

A)



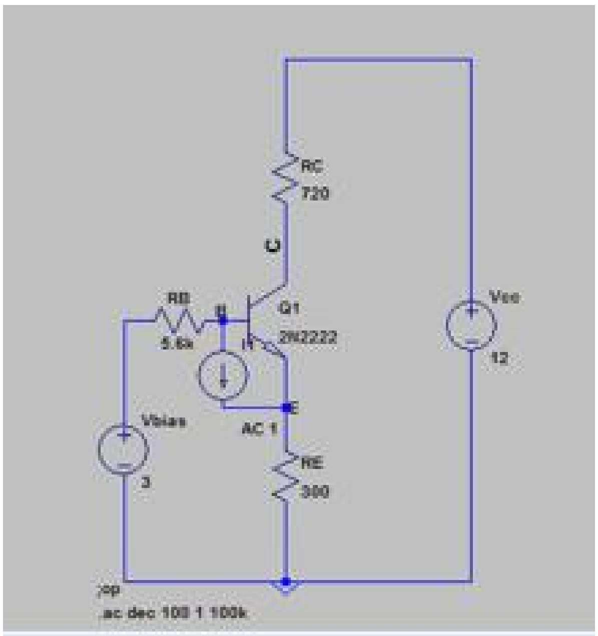

Με DC op. βλέπουμε πως Vbias = 3V

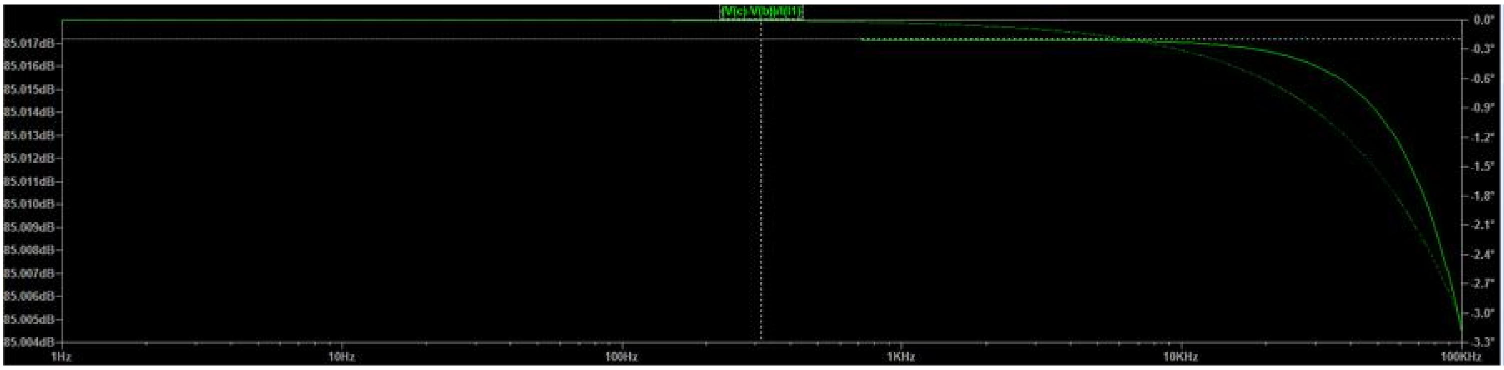


B)

Τοποθετώ μεταξύ βάσης και εκπομπού δοκιμαστική πηγή ρεύματος Ix και ισχύει ότι: Rbe = Vbe/Ix

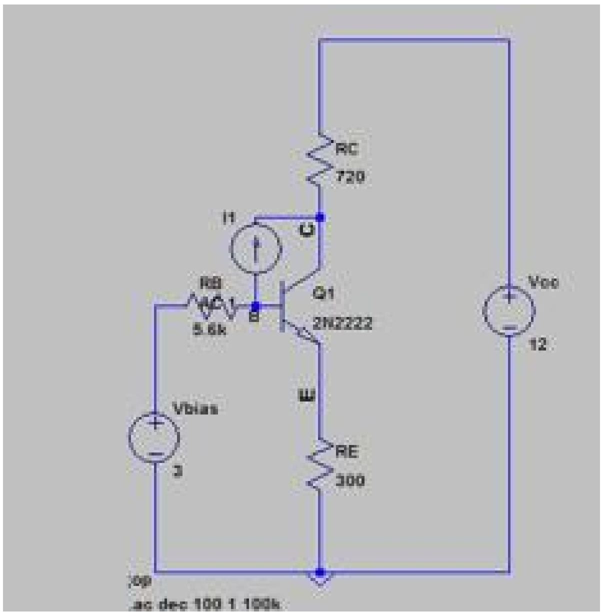


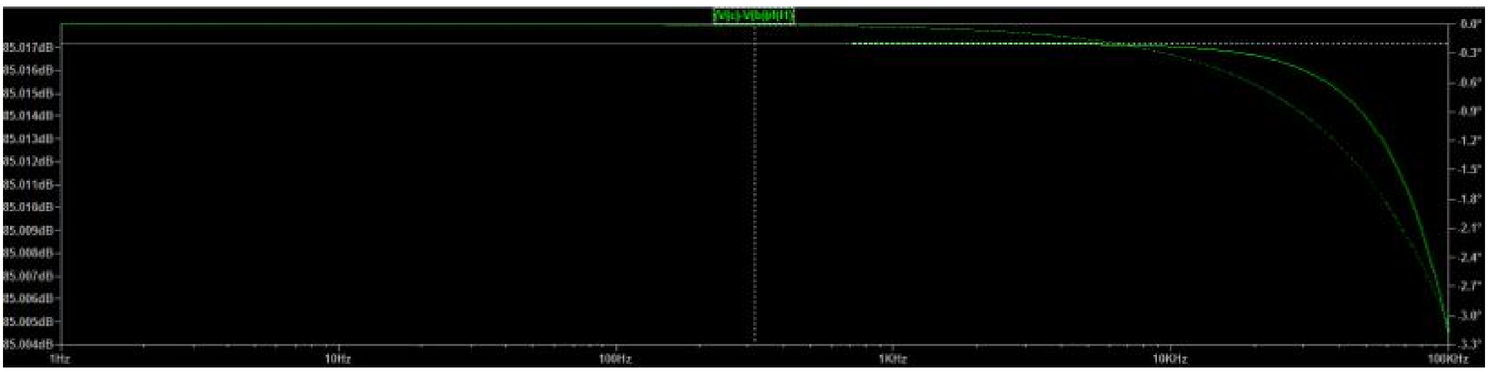



$R_{be} = 75.5\ \Omega$

Γ)

Αντίστοιχα για τον υπολογισμό της Rbc:




$R_{be} = 17.78\ k\Omega$