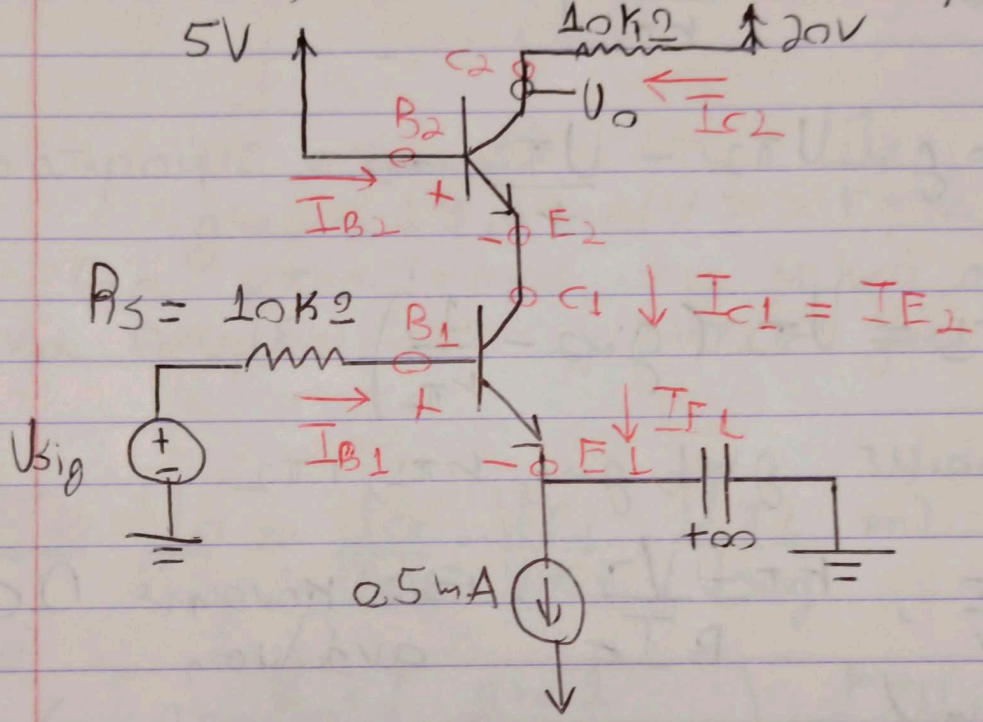
Ηλεκτρονική ΙΙ
5η Σειρά Ασκήσεων - 2022

Κωνσταντίνος Ιωάννου
ΑΜ: 03119840

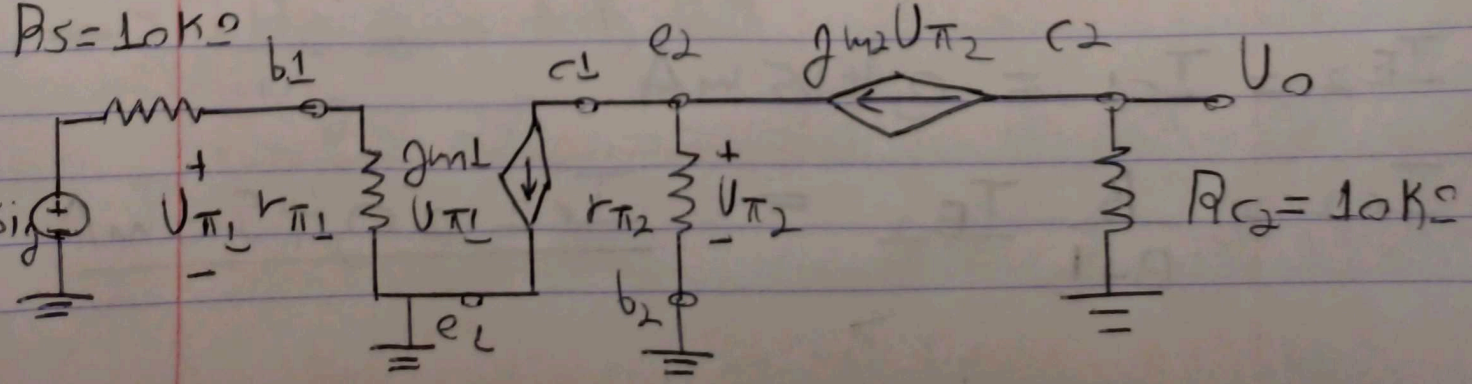
Ασκ 8.101

(b) $\beta = 100$, $r_o \to +\infty$, Συνολικά Κέρδος Τάσης



Θεωρούμε $V_{BE1} = V_{BE2} = 0,7V$
(ορθή ενεργό περιοχή)

- Αντικαθιστώντας π-μοντέλο Α.Σ
  Ac ανάλυση C → Βραχυκύκλωμα
  Μηδενίζω DC πηγές



από όλη $V_o = (-g_{m2} V_{\pi 2}) R_C$ (1)

Από διαίρεση τάσης $V_{\pi 1} = \frac{r_{\pi 1}}{r_{\pi 1} + R_s} V_{sig}$ (2)

Ακόμη

$$\left.\begin{aligned} i_{C1} &= g_{m1} V_{\pi 1} \\ i_{C2} &= g_{m2} V_{\pi 2} \end{aligned}\right| \Rightarrow$$

$$i_{C1} = g_{m2} V_{\pi 2} - \frac{V_{\pi 2}}{r_{\pi 2}}$$

$$g_{m1} V_{\pi 1} = g_{m2} V_{\pi 2} - \frac{V_{\pi 2}}{r_{\pi 2}} \Leftrightarrow$$

$$g_{m1} V_{\pi 1} = V_{\pi 2} \left(g_{m2} - \frac{1}{r_{\pi 2}} \right) \quad (3)$$

- Για να βρούμε $g_{m1}, g_{m2}, r_{\pi 1}, r_{\pi 2}$

$g_m = \frac{I_C}{V_T}$, $r_\pi = \frac{V_T}{\beta I_C}$ Θα κάνουμε DC ανάλυση

με $V_T = 25\,mV$

DC ανάλυση $C \rightarrow$ ανοιχτοκύκλωμα

μηδενίζω AC πηγές $\rightarrow V_{sig} = 0$

προφανώς $I_{E1} = 0,5\,mA$

$I_{C1} = \frac{\beta}{\beta + 1} I_{E1} \Rightarrow \underline{I_{C1} = 0,495\,mA}$

$I_{E2} = I_{C1} = 0,495\,mA$

$I_{C2} = \frac{\beta}{\beta + 1} I_{E2} \Rightarrow \underline{I_{C2} = 0,490\,mA}$

$g_{m1} = \frac{I_{C1}}{V_T} \rightarrow g_{m1} = 19{,}8\ mA/V$

$g_{m2} = \frac{I_{C2}}{V_T} \rightarrow g_{m2} = 19{,}6\ mA/V$

Θεωρούμε $g_{m1} \simeq g_{m2} \simeq g_m \simeq 19{,}7\ mA/V$

$r_{\pi 1} \simeq r_{\pi 2} = \frac{\beta}{g_m} \rightarrow r_\pi \simeq 5{,}07\ K\Omega$

Παρατηρούμε στην (3) ότι $\frac{1}{g_{m2}} = 19{,}7\ mA/V >> r_\pi = 0{,}197\ mA/V$

Θα μπορούσαμε για μικρό σφάλμα να θεωρήσουμε $g_{m1} V_{\pi 1} \simeq g_{m2} V_{\pi 2}$ (3)'

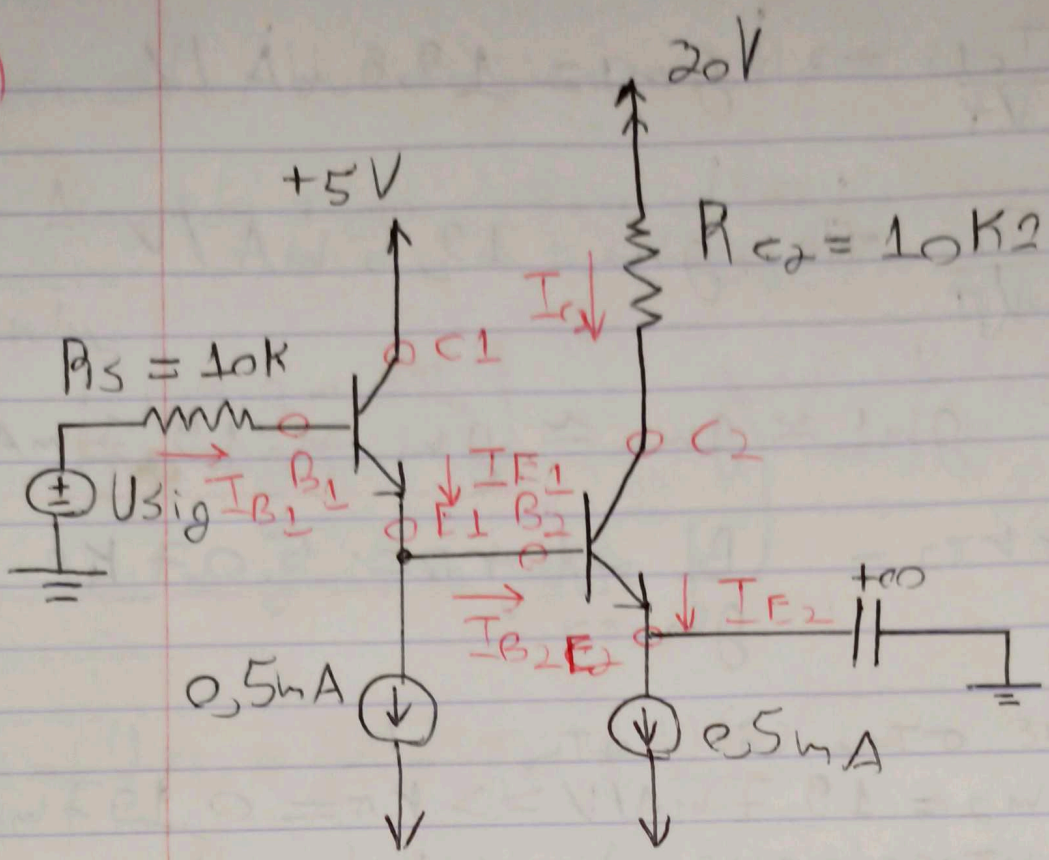
(3) $\frac{V_o}{V_{sig}} = \frac{V_o}{V_{\pi 2}} \frac{V_{\pi 2}}{V_{\pi 1}} \frac{V_{\pi 1}}{V_{sig}} \Rightarrow$

$$\frac{V_o}{V_{sig}} = (-g_{m2} R_c)\left(\frac{g_{m1}}{g_{m2} - \frac{1}{r_{\pi 2}}}\right)\frac{r_{\pi 1}}{r_{\pi 1} + R_s}$$

$$= (-19{,}6 \cdot 10^{-3} \cdot 10^{4})\left(\frac{19{,}8}{19{,}6 - 0{,}197}\right)\cdot\frac{5{,}07\,10^{3}}{5{,}07 \cdot 10^{3} + 10 \cdot 10^{3}}$$

$$\rightarrow \boxed{\frac{V_o}{V_{sig}} = -67{,}29}$$

(d)



• DC Ανάλυση C → ανοιχτοκύκλωμα
U_{sig} → βραχυκύκλωμα

$\underline{I_{E2} = 0,5mA}$

$$I_{EL} = 0,5mA + I_{B2} = 0,5mA + \frac{0,5mA}{B+1}$$

$$\Rightarrow \underline{I_{E1} = 0,505mA}$$

$$g_{m1} = \frac{I_{C1}}{V_T} = 0,0198 \frac{A}{V}$$

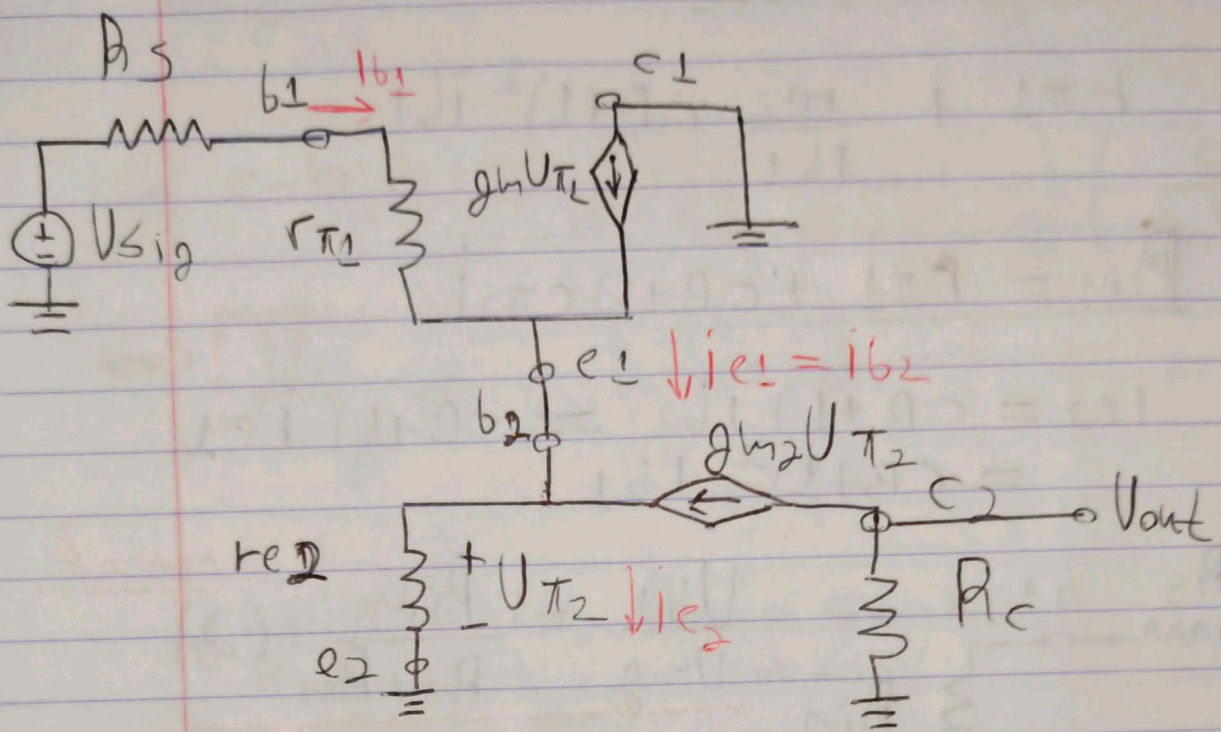
$$g_{m2} = \frac{I_{C2}}{V_T} \simeq 0,0198 \frac{A}{V}$$

$$r_{\pi 1} = \frac{B}{g_m} \simeq 5,05K\Omega \quad r_{e2} = \frac{r_{\pi 2}}{B+1} = 50\Omega$$

$$r_{\pi 2} = 5,05K\Omega$$

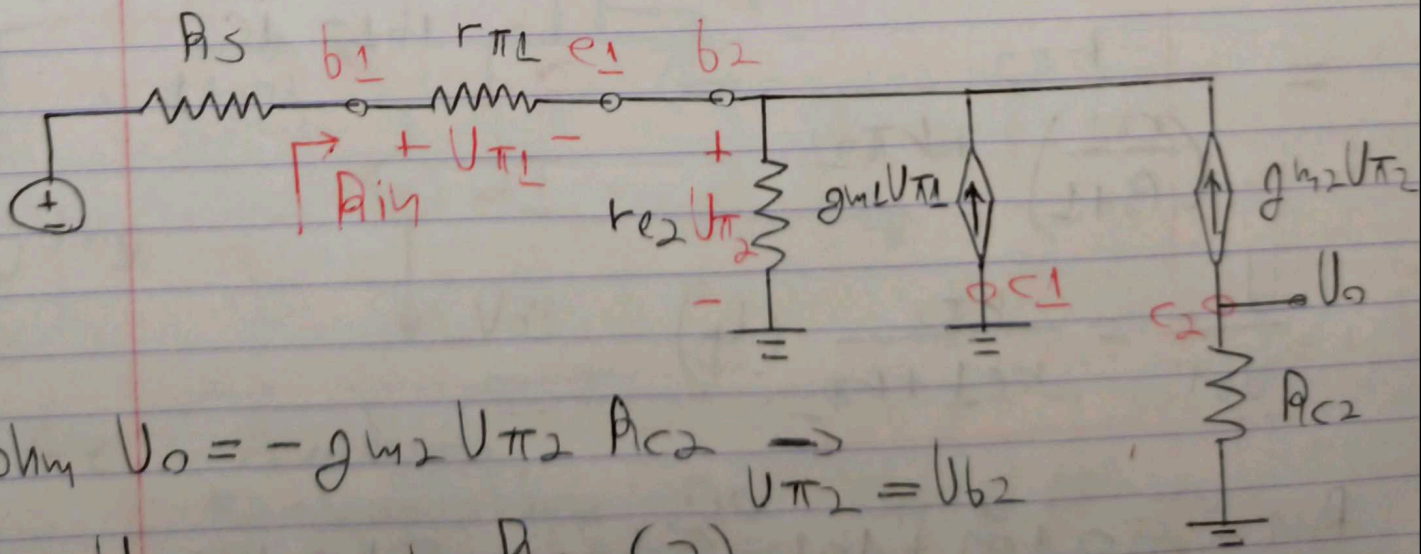
Ac Ανάλυση - π και Τ μοντέλα Α.Σ

Dc πηγές → μηδενίζονται
C → Βραχυκύκλωμα



$$\frac{V_o}{V_{sig}} = \frac{V_o}{V_{b2}} \cdot \frac{V_{b2}}{V_{b1}} \cdot \frac{V_{b1}}{V_{sig}} \quad (1)$$

=> απλοποίηση → $i_{e1} = i_{b2}$



ohm $V_o = -g_{m2} V_{\pi 2} R_{c2}$ → $V_{\pi 2} = V_{b2}$

$$\frac{V_o}{V_{b2}} = -g_{m2} R_{c2} \quad (2)$$

Υπενθύμιση: $r_\pi = (\beta+1)\, r_e$

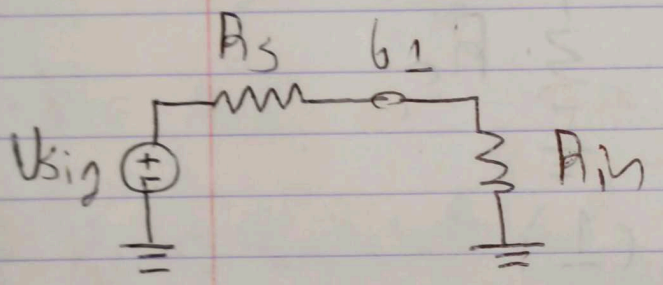
$$R_{in} = \frac{v_{b1}}{i_{b1}} = \frac{r_{\pi 1} i_{b1} + r_{e2} i_{e2}}{i_{b1}}$$

$$= r_{\pi 1} + \frac{r_{e2}}{i_{b1}} (\beta+1)^2 i_{b1}$$

$$\Rightarrow \boxed{R_{in} = r_{\pi 1} + (\beta+1) r_{\pi 2}}$$

Αφού $i_{e2} = (\beta+1) i_{b2} = (\beta+1) i_{e1}$

$$= (\beta+1)^2 i_{b1}$$



$$\frac{v_{b1}}{v_{sig}} = \frac{R_{in}}{R_s + R_{in}} \quad (2)$$

$$\frac{v_{b2}}{v_{b1}} = \frac{r_{e2} i_{e2}}{r_{\pi 1} i_{b1} + r_{e2} i_{e2}}$$

$i_{e2} = (\beta+1) i_{b2} \Rightarrow i_{b2} = i_{e1}$

$i_{b1} = \frac{i_{e1}}{\beta+1}$

$$= \frac{r_{\pi 2}}{\left(\frac{r_{\pi 1}}{\beta+1}\right) + r_{\pi 2}} \Leftarrow$$

$$\frac{v_{b2}}{v_{b1}} = \frac{r_{\pi 2}}{r_{e1} + r_{\pi 2}} \quad (4)$$

$$R_{in} = 50 \cdot 10^2 + 101 \cdot 5 \cdot 10^3 = 510\ k\Omega$$

Αντικαθιστώ (2), (3), (4) στην (1)

$$\Rightarrow \frac{U_o}{U_{sig}} = (-g_{m2} R_{C2}) \left(\frac{r_{\pi 2}}{r_{e1} + r_{\pi 2}}\right) \left(\frac{R_{in}}{R_S + R_{in}}\right)$$

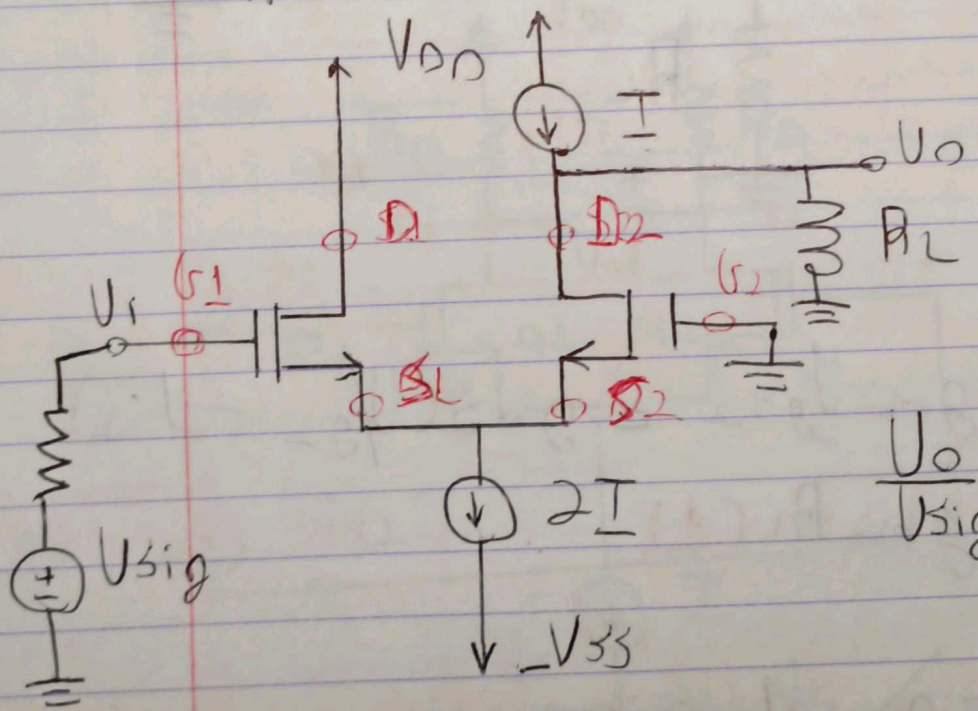
$$= (-0,0198 \cdot 10^4) \left(\frac{5 \cdot 10^3}{5 \cdot 10^3 + 50}\right) \left(\frac{510 \cdot 10^3}{10^4 + 510 \cdot 10^3}\right)$$

$$\Rightarrow \boxed{\frac{U_o}{U_{sig}} = -192,27}$$

Άσκηση 8.100

$g_m = 5\ mA/V$, $R_{sig} = 500K\Omega$

$R_L = 10K\Omega$, $r_o \to +\infty$



$$\frac{U_o}{U_{sig}} = ?$$

• AC Ανάλυση

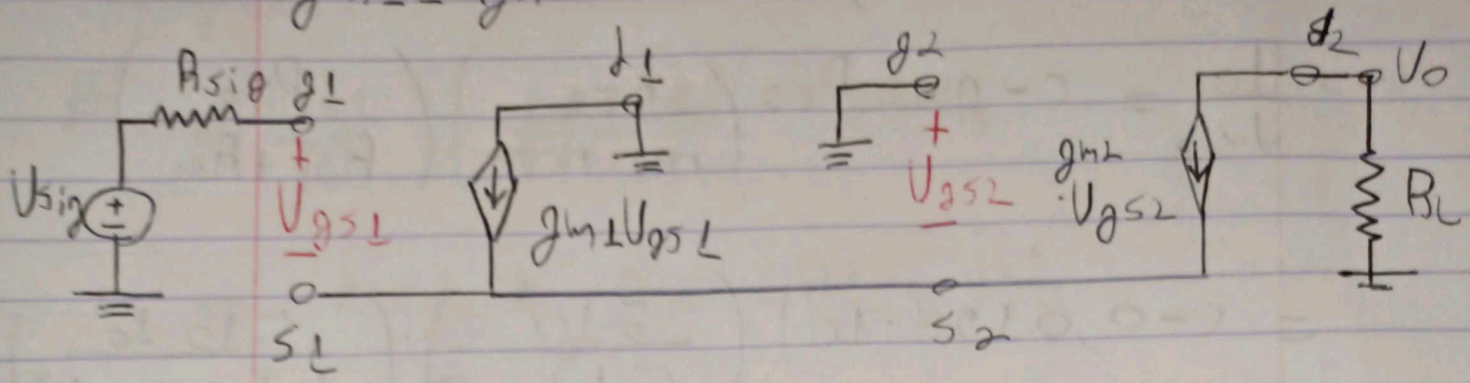
Βραχυκυκλώνω DC πηγές τάσης

Ανοιχτοκυκλώνω πηγές DC ρεύματος

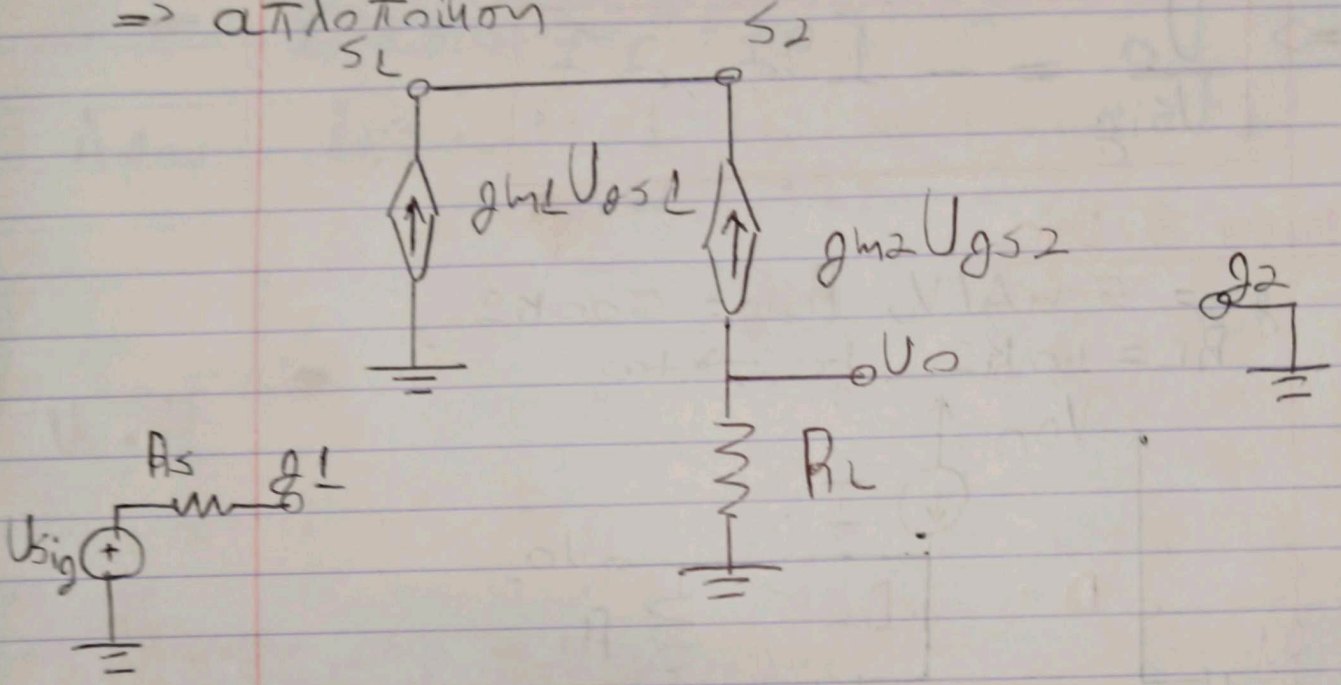
Αντικαθιστώντας με π μοντέλα

τα n-MOS (Ασθενούς σήματος)

$g_{m1} = g_{m2}$



$\Rightarrow$ απλοποίηση



ολμ $0 - V_o = g_{m2} V_{gs2} = g_{m2}(V_{g2}^{\nearrow 0} - V_{s2})$

$\Leftrightarrow \frac{V_o}{V_{s2}} = g_{m2} R_L$ (1)

$g_{m1} V_{gs1} = -g_{m2} V_{gs2} \Leftrightarrow$

$V_{g1} - V_{s1} = -V_{g2} + V_{s2} \Leftrightarrow$

$V_{g1} = 2V_{s1} = 2V_{s2}$ (2)

Τέλος $V_{sig} - V_{g1} = I_{g1} R_{sig}$ $\xrightarrow{I_{g1} \approx 0}$ (από θεωρία)

$V_{sig} = V_{g1}$ (3)

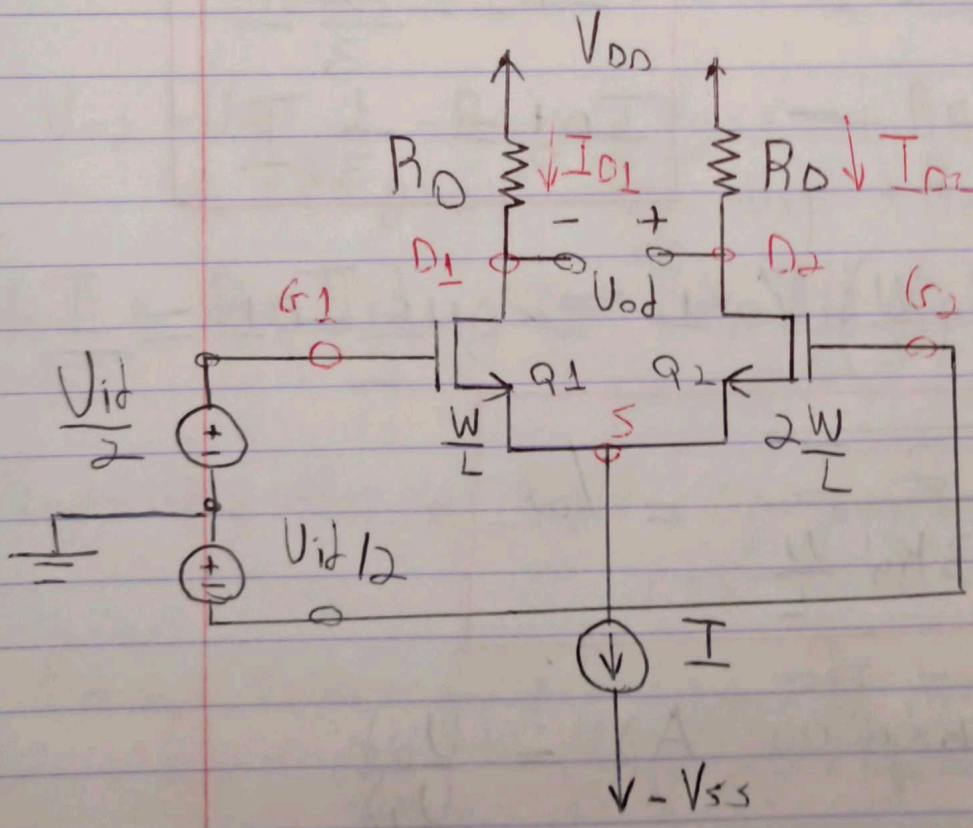
Από (1), (2), (3)

$$\frac{V_o}{V_{sig}} = \frac{V_o}{V_{s2}} \cdot \frac{V_{s1}}{V_{g1}} = \frac{R_L g_m}{2} = 25$$

Άσκηση 9.24

$$\left(\frac{W}{L}\right)_2 = 2\left(\frac{W}{L}\right)_1$$

Vid μικρό ημιτονοειδές σήμα



α) I_{D1}, I_{D2}

$$I_{D1} = \frac{1}{2} K_n' \left(\frac{W}{L}\right) V_{ov1}^2 \quad I_{D2} = \frac{1}{2} K_n' \left(2\frac{W}{L}\right) V_{ov2}^2$$

$V_{ov1} = V_{GS1} - V_{th} = -U_S - V_{th}$
$V_{ov2} = V_{GS2} - V_{th} = -U_S - V_{th}$ $\Big| \Rightarrow$

$$V_{ov1} = V_{ov2} = V_{ov}$$

για DC ανάλυση Uid βραχυκυκλώνεται

$$V_{G1} = V_{G2} = 0.$$

οπότε $\frac{I_{D1}}{I_{D2}} = \frac{\frac{1}{2} K_n' \left(\frac{W}{L}\right) V_{ov}^2}{\frac{1}{2} K_n' \left(\frac{W}{L}\right) V_{ov}^2} \Rightarrow \frac{I_{D1}}{I_{D2}} = \frac{1}{2}$

Από ΝΡΚ στον κόμβο S

$$I_{D1} + I_{D2} = I \Rightarrow$$

$$\frac{I_{D2}}{2} + I_{D2} = I \Rightarrow \boxed{I_{D2} = \frac{2}{3} I}$$

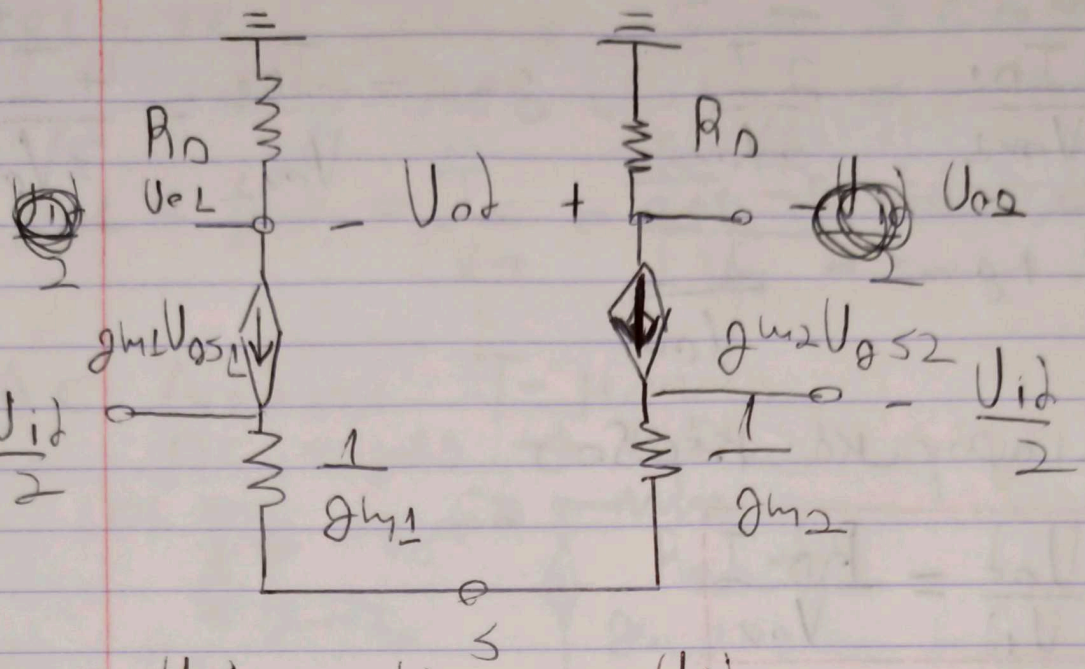
προφανώς $\Rightarrow$ $\boxed{I_{D1} = \frac{1}{3} I}$

β) $I_{D1} = \frac{1}{2} K_n' \left(\frac{W}{L}\right) V_{ov1}^2 \Leftrightarrow$ με $I_{D1} = \frac{I}{3}$

$$\boxed{V_{ov1} = \sqrt{\frac{2I}{3 K_n' \frac{W}{L}}} = V_{ov2}}$$

γ) Διαφορική κέρδος $A_d = \frac{U_{od}}{U_{id}}$

Αντιστάθμιση Ac Μοντέλο - Τ μοντέλο
Μυδενίζω Dc πηγές



$$V_{g1} = \frac{V_{id}}{2}, \quad V_{g2} = -\frac{V_{id}}{2}$$

$$V_{o2} - V_{o1} = -R_D g_{m2} V_{GS2} + R_D g_{m1} V_{GS1}$$
$$= -R_D g_{m2}\left(-\frac{V_{id}}{2} - V_S\right) + R_D g_{m1}\left(\frac{V_{id}}{2} - V_S\right) \leftarrow$$

$$V_{od} = R_D \frac{V_{id}}{2} g_{m2} + R_D \frac{V_{id}}{2} g_{m1} + V_S R_D (g_{m2} - g_{m1})$$

$$V_{od} = V_{o2} - V_{o1} = \frac{R_D}{2} V_{id} (g_{m1} + g_{m2}) + V_S R_D (g_{m2} - g_{m1}) \quad (1)$$

Εστω $V_S \neq 0$ $\rightarrow$ $V_{id}/2 - V_S = r \cdot I$ $\leftarrow$
$V_S + V_{id}/2 = r \cdot I$

$2V_S = 0 \Rightarrow V_S = 0$
(ελλειπής γείωση)

Από (1)
$\rightarrow$

$$\boxed{\frac{V_{od}}{V_{id}} = \frac{R_D}{2}(g_{m1} + g_{m2})}$$

$$g_m = \frac{2I_D}{V_{OV}}$$

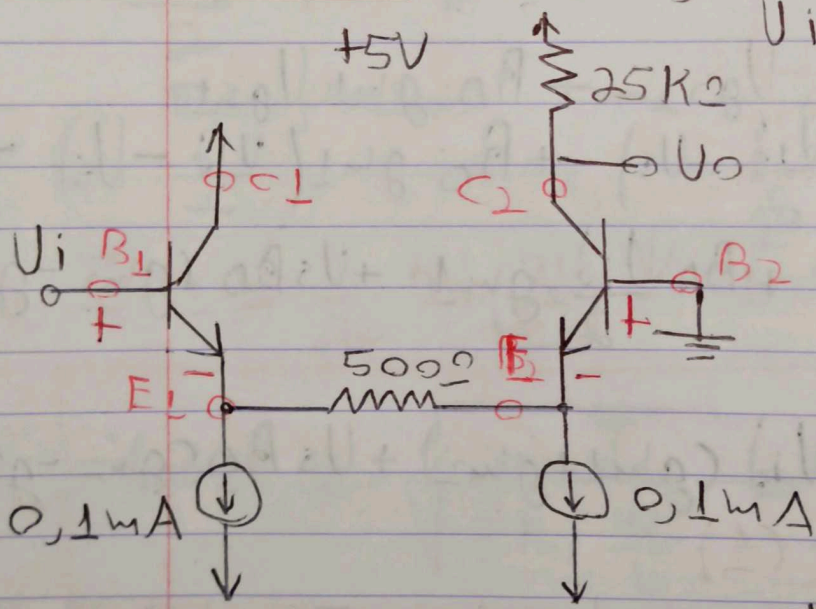
$$g_{m1} = \frac{2I_{D1}}{V_{OV1}} = \frac{2I}{3V_{OV}}, \quad g_{m2} = \frac{2I_{D2}}{V_{OV2}} = \frac{4I}{3V_{OV}}$$

$$g_{m1} + g_{m2} = \frac{2I}{V_{OV}}$$

Άρα Διαφορική κέρδος

$$\boxed{A_d = \frac{V_{od}}{V_{id}} = \frac{R_D \cdot I}{V_{OV}}}$$

Άσκηση 9.53 $R_{in} = ;$, $\frac{V_o}{V_i} = ;$ $\beta = 100$



• DC Ανάλυση Μηδενίζω $V_i = 0$ (AC πηγή)

ΝΤΚ

$$V_{B1E1} - V_{B2E2} = 500\, I_{E1 \to E2}$$
$$V_{B1E1} = V_{B2E2} = 0,7V$$

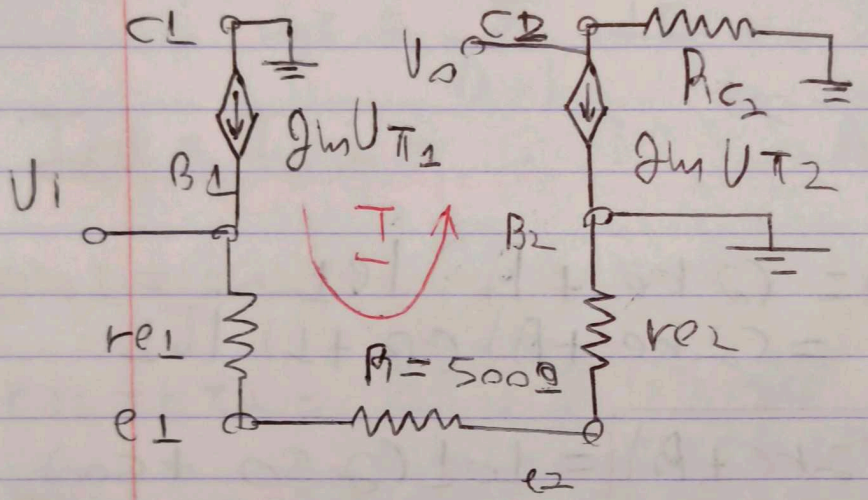
$$\Rightarrow I_{E1 \to E2} = 0$$

άρα $I_{E1} = I_{E2} = 0,1\,mA$

$$r_{e1} = r_{e2} = \frac{V_T}{I_{E1,2}} = \frac{25}{0,1} = 250\,\Omega$$

$$g_{m1} = g_{m2} = \frac{I_C}{V_T} = \frac{\frac{\beta}{\beta+1} I_E}{V_T} = 0,00396\,\frac{A}{V}$$

- AC Ανάλυση T-μοντέλο
  DC πηγές → Μηδενίζω

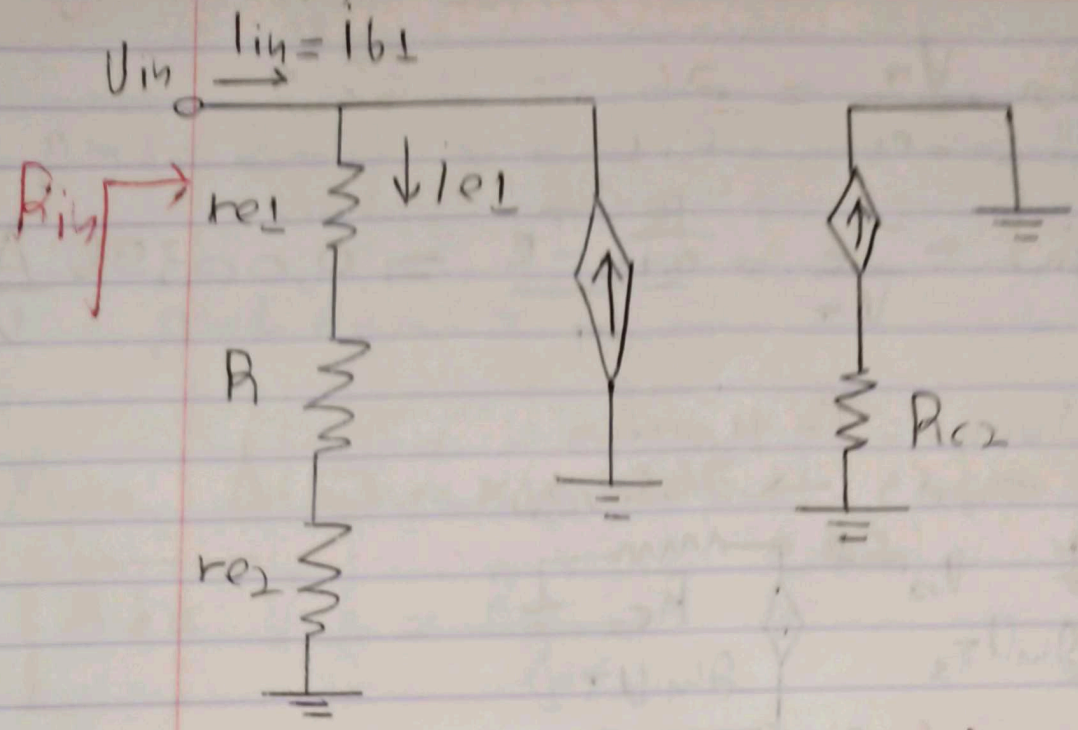


- $V_o = -g_m R_{c2} V_{\pi 2} = I R_{c2}$
- $V_i - V_{b2} = I(r_{e1} + r_{e2} + R)$ (→ 0)
- $I = g_m V_{\pi 1} = -g_m V_{\pi 2}$

Κέρδος $A = \frac{V_o}{V_i} = \frac{R_{c2}}{2r_e + R} = \frac{25 \cdot 10^3}{2 \cdot 250 + 500}$

$$\rightarrow \boxed{A = \frac{V_o'}{V_i} = \frac{R_{c2}}{2r_e + R} = 25}$$

Απλοποιημένο



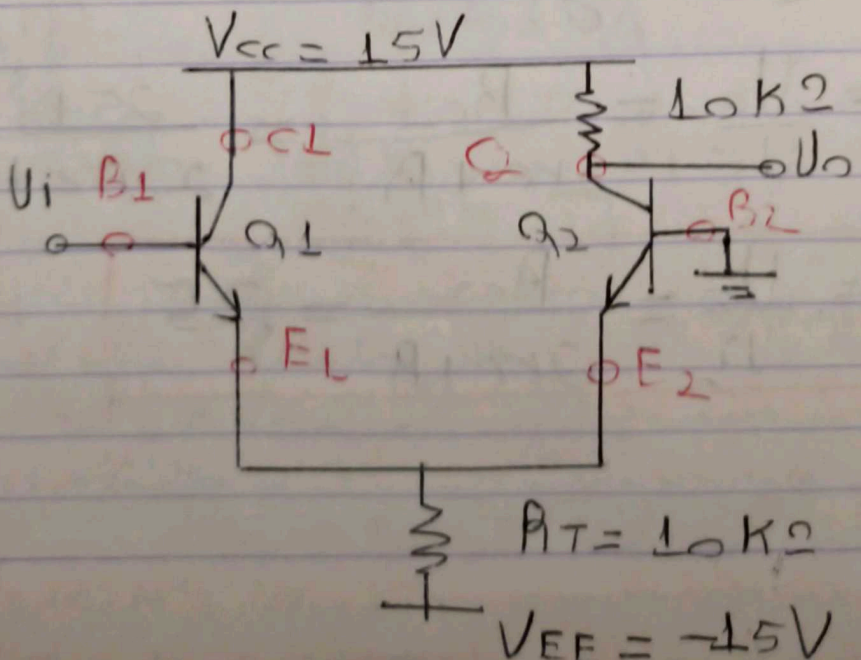
$R_{in} = \frac{V_{in}}{I_{in}}$, $V_{in} = (2r_e + R)\, i_{e1}$

$= (2r_e + R)(\beta + 1)\, i_{b1}$

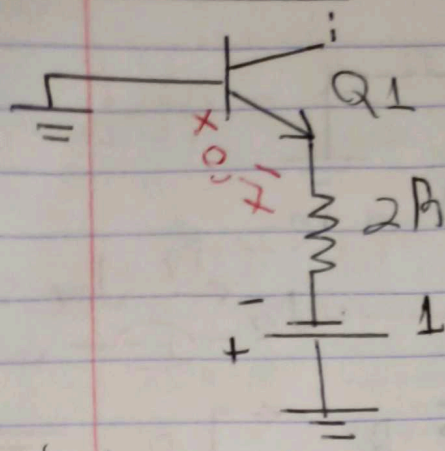
$R_{in} = (\beta + 1)(2r_e + R) = 101\,(2 \cdot 50 + 500)$

$\rightarrow R_{in} = 101\,K\Omega$

Άσκηση 5 R_{in}, $\frac{V_o}{V_{in}}$, R_{out}



DC Ανάλυση (Μηδενίζω Vin)



Από ΚΤΚ

$-0,7+15=2R_T \cdot I_{E1}$

$I_{E1}=\frac{15-0,7}{2\cdot 10\cdot 10^3}$

Ομοίως για Q2 $\Rightarrow$ $I_{E1}=I_{E2}=0,715\,mA$

$I_C=\frac{B}{B+1} I_E \Rightarrow$

$I_{C1}=I_{C2}=0,708\,mA$

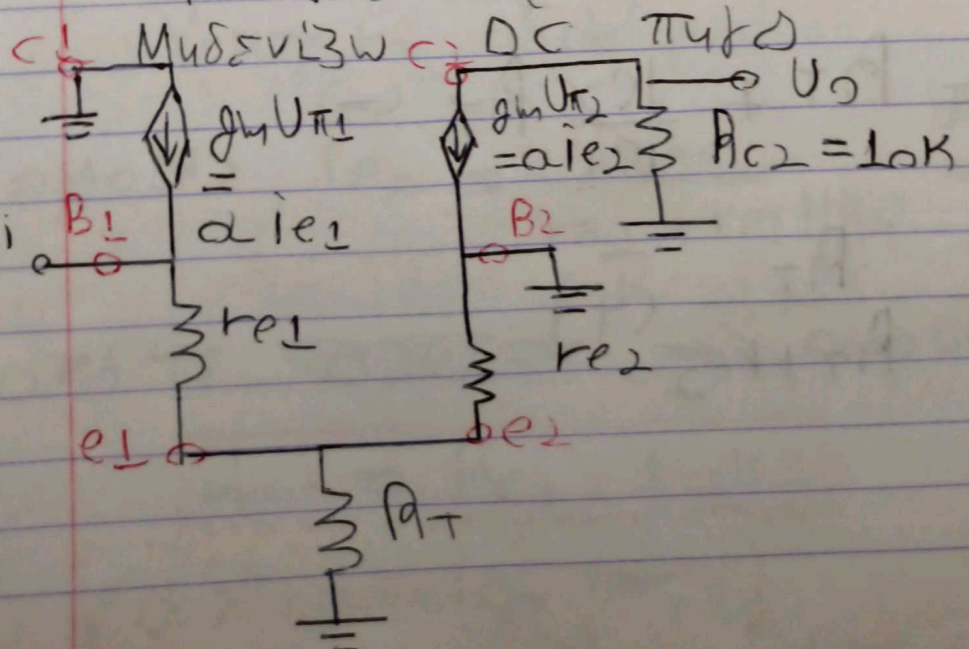
$g_{m1}=g_{m2}=\frac{I_C}{V_T}=0,02832\,\frac{A}{V}$

$r_{\pi 1}=r_{\pi 2}=\frac{B}{g_m}=3,53\,K\Omega$

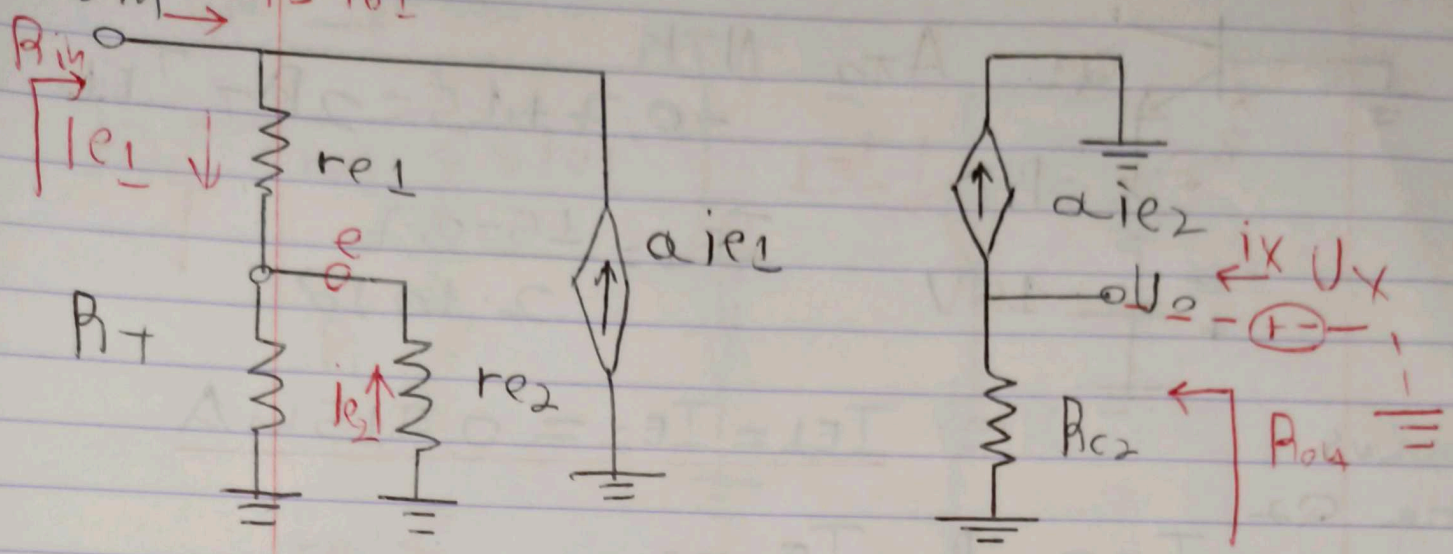
$r_{e1}=r_{e2}=\frac{B}{B+1}\frac{1}{g_m}=34,96\,\Omega$

α) AC Ανάλυση χωρίς φ. Early

Τ-ισοδύναμο



Απλοποίηση



ohm $V_o = -\alpha i_{e_2} R_{C_2}$ (1)

ohm $V_{in} = r_{e_1} i_{e_1} + (R_T \| r_{e_2}) i_{e_1}$ (2)

$$\frac{V_o}{V_{in}} = \frac{-\alpha R_{C_2}}{r_{e_1} + R_T \| r_{e_2}} \left(\frac{i_{e_2}}{i_{e_1}} \right) \quad (3)$$

$$\left.\begin{aligned} V_{e_2} &= -r_{e_2} i_{e_2} \\ V_{e_2} &= (i_{e_1} + i_{e_2}) R_T \end{aligned}\right| \Rightarrow$$

$$-r_{e_2} i_{e_2} = i_{e_1} R_T + i_{e_2} R_T \Leftrightarrow$$

$$-r_{e_2} \frac{i_{e_2}}{i_{e_1}} = R_T + \frac{i_{e_2}}{i_{e_1}} R_T \Leftrightarrow$$

$$\frac{i_{e_2}}{i_{e_1}} = -\frac{R_T}{R_T + r_{e_2}} \quad (4)$$

Από (3), (4) ⇒

$$\boxed{\frac{U_o}{U_{in}} = \frac{\alpha R_{c2}}{r_{e1} + R_T \| r_{e2}} \cdot \frac{R_T}{R_T + r_{e2}}}$$

$$\frac{U_o}{U_{in}} = \frac{\frac{100}{101} \cdot 10^4}{35 + \frac{35 \cdot 10^4}{35 + 10^4}} \cdot \frac{10^4}{10^4 + 35} \Leftrightarrow \boxed{\frac{U_o}{U_{in}} = 141,195}$$

Κέρδος Τάσης

Από (2)

$$U_{in} = i_{e1}(r_{e1} + R_T \| r_{e2})$$

άμεσως $i_{e1} = (\beta + 1) i_{b1} = (\beta + 1) i_{in}$ ⇒

$$\boxed{R_{in} = \frac{U_{in}}{I_{in}} = (\beta + 1)(r_{e1} + R_T \| r_{e2})}$$

$$R_{in} = 101 \cdot \left(35 + \frac{35 \cdot 10^4}{35 + 10^4}\right) \Leftrightarrow \boxed{R_{in} = 7,057 K\Omega}$$

- $R_{out} = \frac{U_x}{I_x}$, μηδενίζουμε είσοδο $U_{in} = 0$
Θέτουμε τάση στην έξοδο U_x

Από (2) για $U_{in} = 0 \Rightarrow i_{e1} = 0$
άρα το αριστερό κύκλωμα
ηλεκτρικά αδιάφορο

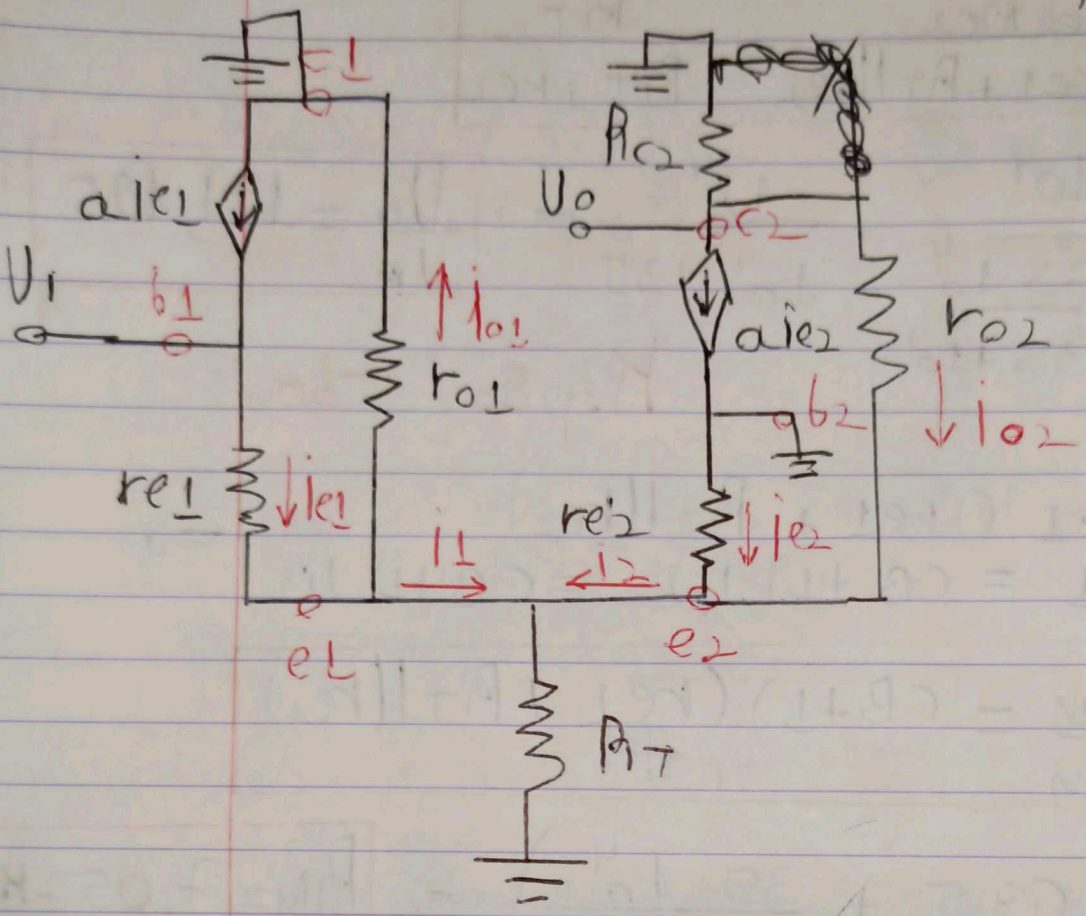
ομοίως $i_{e2} = \frac{U_{in} - 0}{r_{e2} + r_{e1} \| R_T}$ $\xrightarrow{U_{in}=0}$ $i_{e2} = 0$

οπότε $\alpha i_{e2} = 0 \Rightarrow$ ανοιχτοκυκλώνεται

$$\boxed{R_{out} = R_{c2} = 10 K\Omega}$$

$(\alpha i_{e1} = \alpha i_{e2} = 0)$

B) AC Ανάλυση με φ. Early (T μοντέλο), DC πηγές μηδενίζονται



$$r_{o1} = r_{o2} = \frac{|V_A|}{I_C} = 70\,K\Omega$$

Εστω $V_A = 50$ με $100\,V$ (δεν δίνεται)

$$I_{e2} = \frac{0 - V_e}{r_{e2}}, \quad I_{e1} = \frac{V_{in} - V_e}{r_{e1}}$$

$$I_{o2} = \frac{V_o - V_e}{r_{o2}}, \quad I_{o1} = \frac{V_e - 0}{r_{o1}}$$

ΝΤΚ $I_{Rc2} = I_{o2} + \alpha I_{e2} \Rightarrow$

$$\frac{0 - V_o}{R_{c2}} = \frac{V_o - V_e}{r_{o2}} - \frac{V_e}{r_{e2}} \alpha \Rightarrow$$

$$-V_o \left(\frac{1}{R_{c2}} + \frac{1}{r_{o2}} \right) = -V_e \left(\frac{\alpha}{r_{e2}} + \frac{1}{r_{o2}} \right) \Rightarrow$$

$$\frac{V_o}{R_{c2} \| r_{o2}} = \frac{V_e}{r_{o2} \| \frac{r_{e2}}{\alpha}} \Rightarrow$$

$$\frac{V_o}{V_e} = \frac{R_{c2} \| r_{o2}}{r_{o2} \| \frac{r_{e2}}{\alpha}} = \frac{\frac{\alpha}{r_{e2}} + \frac{1}{r_{o2}}}{\frac{1}{R_{c2}} + \frac{1}{r_{o2}}}$$

Για ευκολία στις πράξεις θέτω

$$\boxed{\frac{V_o}{V_e} = M} \Rightarrow V_e = \frac{V_o}{M}$$

ΝΡΚ $I_1 + I_2 = I_{RT} \Rightarrow$

$$(I_{e1} - I_{o1}) + (I_{e2} + I_{o2}) = I_{RT} \Rightarrow$$

$$\frac{V_M - V_e}{r_{e1}} - \frac{V_e}{r_{o1}} + \frac{V_o - V_e}{r_{o2}} - \frac{V_e}{r_{e2}} = \frac{V_e}{R_T} \quad \cdot \frac{1}{V_e}$$

$$\frac{\frac{V_{in}}{V_e} - 1}{r_{e1}} - \frac{1}{r_{o1}} + \frac{\frac{V_o}{V_e} - 1}{r_{o2}} - \frac{1}{r_{e2}} = \frac{1}{R_T} \quad \frac{V_o = V_e}{}$$

$$M \frac{\frac{V_{in}}{V_o} - 1}{r_{e1}} - \frac{1}{r_{o1}} + \frac{M - 1}{r_{o2}} - \frac{1}{r_{e2}} = \frac{1}{R_T} \Rightarrow$$

$$\frac{V_{in}}{V_o}\frac{M}{r_{e1}} = \left(\frac{1}{R_T} + \frac{1}{r_{e2}} + \frac{1-M}{r_{o2}} + \frac{1}{r_{o1}} + \frac{1}{r_{eL}}\right) \Rightarrow$$

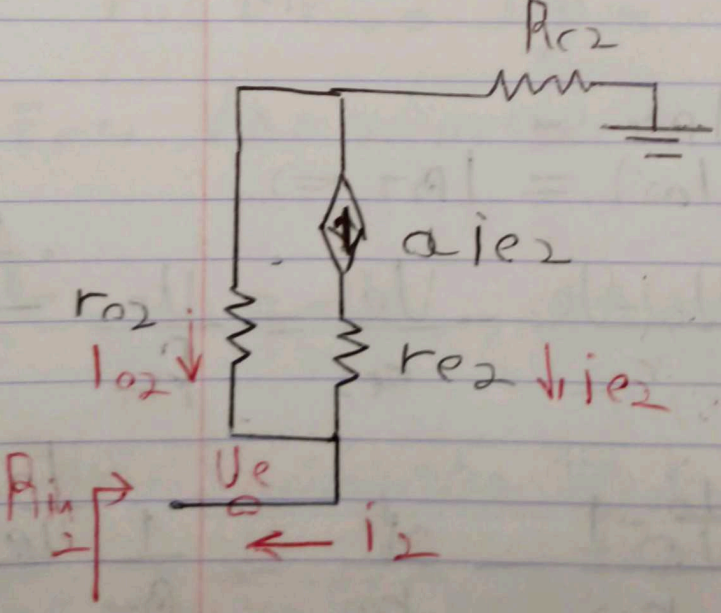
$$\frac{V_{in}}{V_o} = \frac{r_{e1}}{M}\left(\frac{1}{R_T} + \frac{1}{r_{e2}} + \frac{1-M}{r_{o2}} + \frac{1}{r_{o1}} + \frac{1}{r_{eL}}\right)$$

$$\boxed{\frac{V_o}{V_{in}} = \frac{M}{r_{e1}}\left(R_T \| r_{e2} \| \frac{1-M}{r_{o2}} \| r_{o1} \| r_{e1}\right)}$$

$$\boxed{M = \frac{V_o}{V_e} = \frac{R_{c2} \| r_{o2}}{r_{o2} \| \frac{r_{e2}}{\alpha}}}$$ Κέρδος Τάσης

Για $V_T \sim 50V \Rightarrow \frac{V_o}{V_{in}} \sim 130 \frac{V}{V}$

- Αρχικά θα βρούμε αντίσταση εισόδου του Q_2 R_{in2}



$$R_{in2} \triangleq \frac{V_e}{-i_2}$$

$$R_{in2} = \frac{i_{e2} r_{e2}}{-i_2} = -\frac{i_{e2} r_{e2}}{i_{o2} + i_{e2}} \Rightarrow$$ αντικαθιστώ

$$R_{in2} = \frac{\frac{-V_e}{r_{e2}} \cdot r_{e2}}{-\frac{V_e}{r_{e2}} + \frac{V_o - V_e}{r_{o2}}} \cdot \frac{\frac{1}{V_e}}{\frac{1}{V_e}} = \frac{-1}{-\frac{1}{r_{e2}} + \frac{V_o/V_e - 1}{r_{o2}}}$$

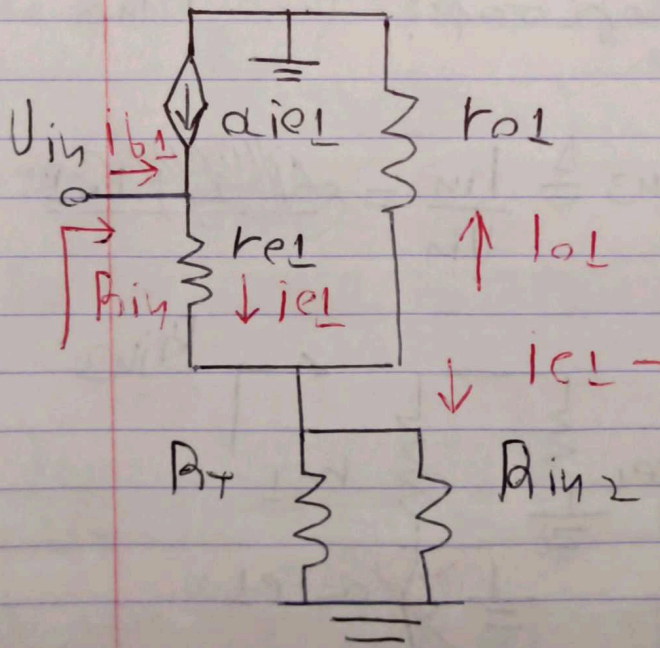
$$M = \frac{V_o}{V_e}$$

$$\frac{1}{\frac{1}{r_{e2}} + \frac{1-M}{r_{o2}}} \rightarrow \boxed{R_{in2} = \frac{1}{\frac{1}{r_{e2}} + \frac{1-M}{r_{o2}}}}$$

$$R_{in2} = \frac{1}{\frac{1}{35} + \frac{1 - \frac{1}{0,004}}{70k}} \Rightarrow \boxed{R_{in2} = 40\Omega}$$

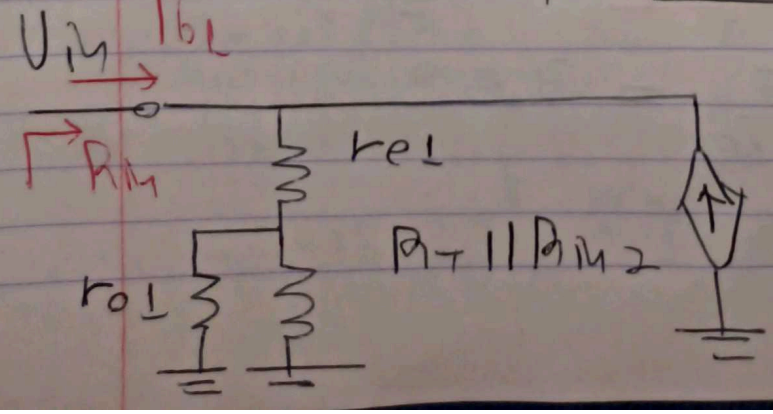
Τώρα λοιπόν έχουμε να βρούμε αντίσταση εισόδου συνολική.

$$R_{in} \triangleq \frac{V_{in}}{i_{b1}}$$



$\Rightarrow$ αντλοπούμε

$$R_{in} = \frac{i_{e1}(r_{e1} + r_{o1} \| R_T \| R_{in2})}{i_{b1}}$$



Με $\frac{i_{e1}}{i_{b1}} = (\beta+1)$

$$\Rightarrow \boxed{R_{in} = (\beta+1)(r_{e1} + r_{o1} \,||\, R_T \,||\, R_{in2})}$$

$$R_{in} = 101\left(35 + \frac{1}{\frac{1}{70k} + \frac{1}{10k} + \frac{1}{40}}\right)$$

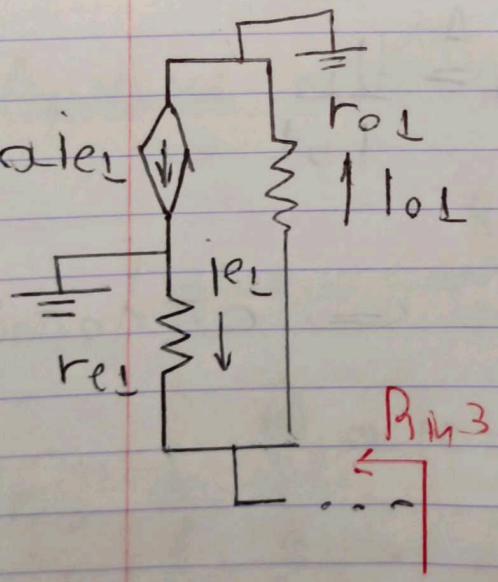
$$\boxed{R_{in} = 7,556\,k\Omega}$$

- Υπολογισμός R_{out}

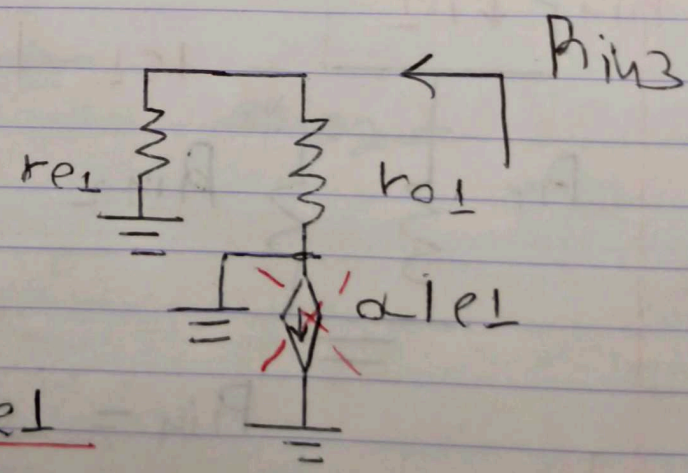
Μηδενίζουμε U_{in}

Τοποθετούμε πηγή τάσης U_X στην έξοδο.

Για ευκολία θα υπολογίσουμε την R_{in3}



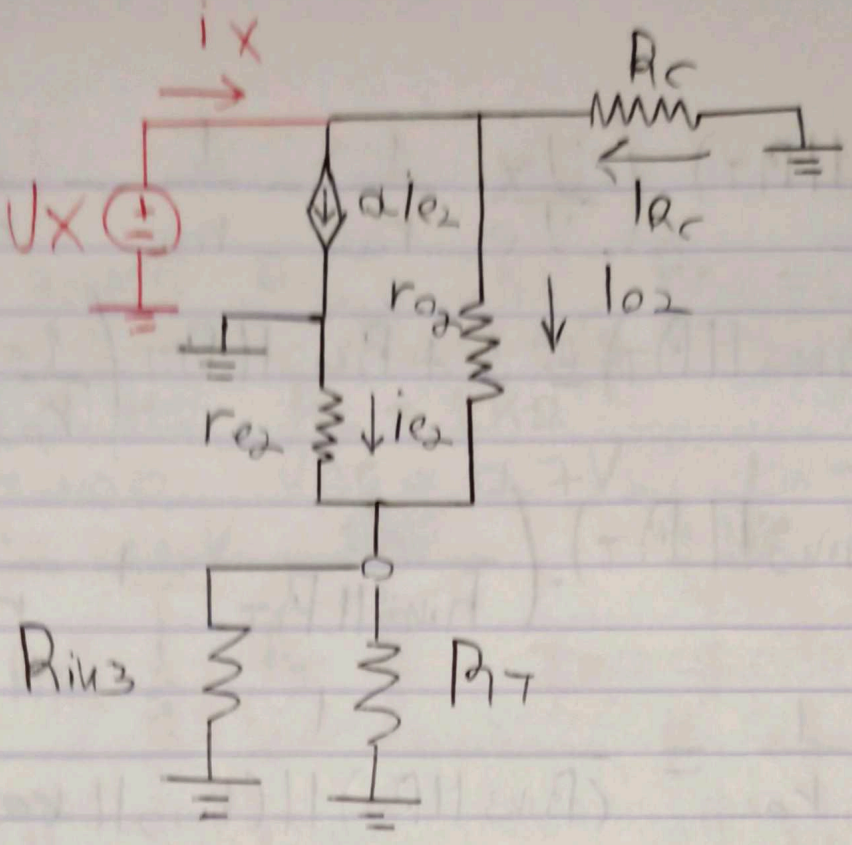
$$R_{in3} \triangleq \frac{i_{in}}{U_{in}} = \text{[illegible]}$$



Άρα $R_{in3} = r_{o1} \,||\, r_{e1}$

$$R_{in3} = \frac{70k \cdot 35}{70k + 35} = 3,5\,\Omega$$

Οπότε



$$I_x = \alpha i_{e2} + I_{o2} - I_{Rc} \quad (1) \quad (\text{ΝΡΚ})$$

$$I_{Rc} = \frac{-U_x}{R_c}, \quad i_{e2} = -\frac{U_{e2}}{r_{e2}}, \quad I_{o2} = \frac{U_x - U_e}{r_{o2}} \quad (2)$$

(ohm)

Από (1), (2) →

$$I_x = \alpha \frac{-U_e}{r_{e2}} + \frac{U_x}{r_{o2}} - \frac{U_e}{r_{o2}} + \frac{U_x}{R_c} \Rightarrow$$

$$\frac{I_x}{U_x} = \frac{-\alpha}{r_{e2}}\left(\frac{U_e}{U_x}\right) - \frac{1}{r_{o2}}\left(\frac{U_e}{U_x}\right) + \frac{1}{r_{o2}} + \frac{1}{R_c} \quad (3)$$

Αρκεί να βρούμε $\frac{U_e}{U_x}$

$$U_e = (R_{in3} \| R_T)(i_{e2} + I_{o2})$$

$$= (R_{in3} \| R_T)\left(\frac{U_x - U_e}{r_{o2}} - \frac{U_e}{r_{e2}}\right) \Rightarrow$$

$$\frac{1}{} = (R_{in3} \| R_T)\left(\frac{U_X}{U_e}\frac{1}{r_{o2}} - \frac{1}{r_{o2}} - \frac{1}{r_{e2}}\right)$$

$$\frac{U_X}{U_e}\frac{1}{r_{o2}}(R_{in3} \| R_T) = 1 + R_{in3} \| R_T\left(\frac{1}{r_{o2}} + \frac{1}{r_{e2}}\right)$$

$$= (R_{in3} \| R_T)\left(\frac{1}{R_{in3} \| R_T} + \frac{1}{r_{o2} \| r_{e2}}\right)$$

$$\Leftrightarrow \frac{U_X}{U_e}\frac{1}{r_{o2}} = \frac{1}{(R_{in3} \| R_T) \| (r_{o2} \| r_{e2})} \Leftrightarrow$$

$$\boxed{\frac{U_e}{U_X} = \frac{(R_{in3} \| R_T) \| (r_{o2} \| r_{e2})}{r_{o2}}} \quad (4)$$

$\frac{U_e}{U_X}$

Από (3), (4) $\Rightarrow$

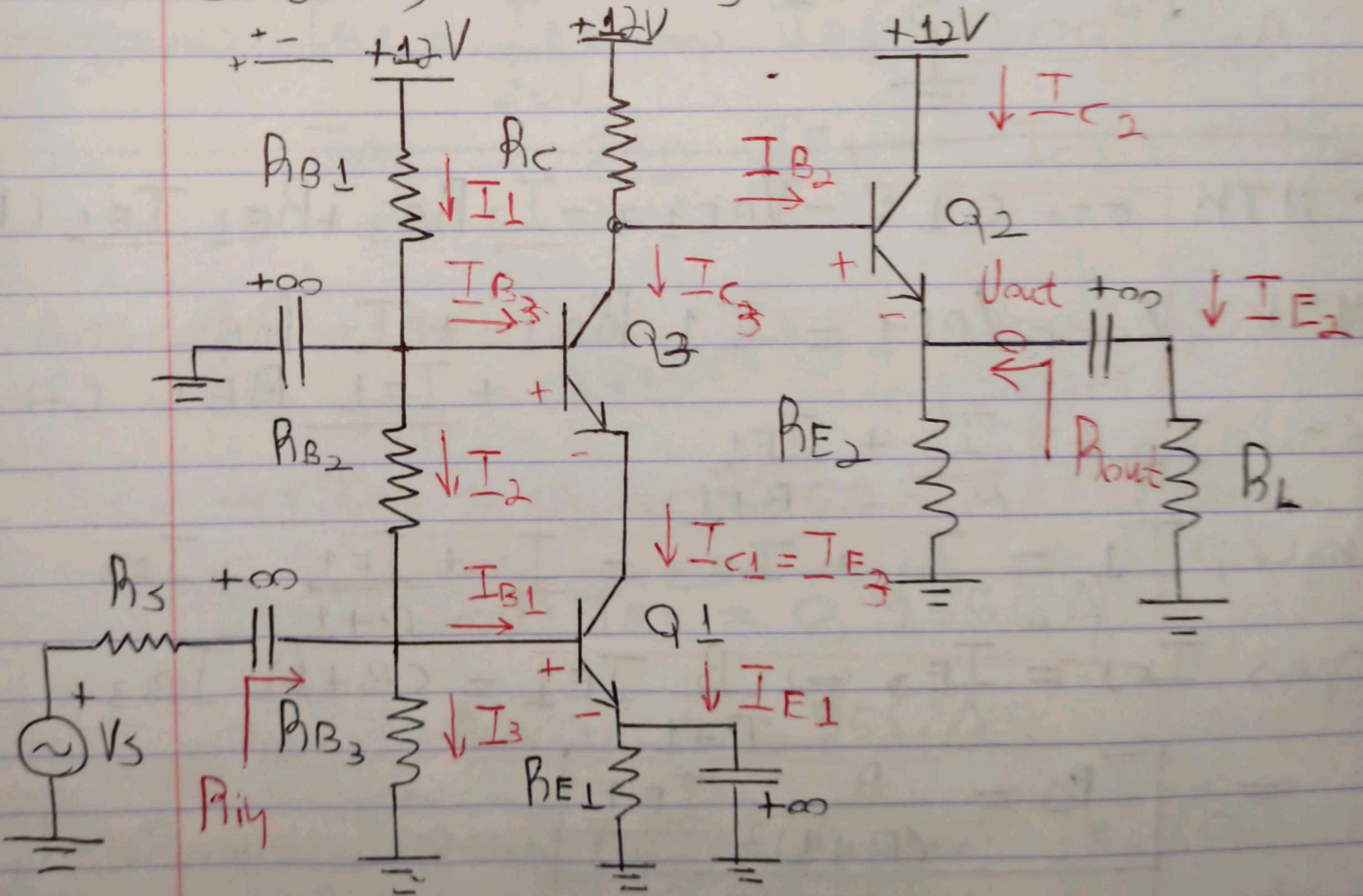
$$\frac{I_X}{U_X} = \frac{1}{R_{c2}} + \frac{1}{r_{o2}} - \frac{\alpha (R_{in3} \| R_T) \| (r_{o2} \| r_{e2})}{r_{o2} \cdot r_{e2}} - \frac{(R_{in3} \| R_T) \| (r_{o2} \| r_{e2})}{r_{o2}^2}$$

$$\boxed{\frac{1}{R_{out}} = \frac{I_X}{U_X}}$$

$\frac{U_e}{U_X} = \ldots$, βρίσκω R_{out} αν μου δίνεται VA.

Άσκηση 6

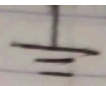
$R_{B1} = 30K\Omega$, $R_{B2} = 6K\Omega$, $R_{B3} = 12K\Omega$
$R_{E1} = 2,3K\Omega$, $R_C = 4K\Omega$, $R_{E2} = 1,8K\Omega$
$R_S = 1K\Omega$, $R_L = 1K\Omega$
$B = 200$, $V_{BE} = 0,7V$, $r_o \to +\infty$



DC Ανάλυση — AC πηγές → Μηδενίζονται
πυκνωτές → ανοιχτο κύκλωμα

$V_{BE1} = V_{BE2} = V_{BE3} = 0,7V$

$R_{...} = (R_{...} \cdot R_{...}) \,||\, R_{B3} \Rightarrow R_{BB} = R_{B12} \cdot R_{B3}$



• ΝΤΚ στο Q1 : $-V_{BE1} = -I_3 R_{B3} + R_{E1} I_{E1}$ (1)

• ΝΤΚ $V_{CC} - V_{BE1} = I_1 R_{B1} + I_2 R_{B2} + I_{E1} R_{E1}$ (2)

όπου $I_2 = I_3 + \frac{I_{E1}}{B+1}$

και $I_1 = I_2 + I_{B3} = I_3 + \frac{I_{E1}}{B+1} + I_{B3}$

• Όμως $I_{C1} = I_{E3} \Leftrightarrow \frac{B}{B+1} I_{E1} = (B+1) I_{B3}$

$$\Rightarrow \boxed{I_{B3} = \frac{B}{(B+1)^2} I_{E1}}$$

(1)' $-0,7 = -I_3 \cdot 12K\Omega + 2,3K\Omega \cdot I_{E1}$

(2)' $12 - 0,7 = \left[I_3 + \frac{I_{E1}}{B+1} + \frac{B}{(B+1)^2} I_{E1} \right] \cdot 30K\Omega + \left(\frac{I_{E1}}{B+1} + I_3 \right) 6K\Omega + I_{E1} \, 2,3K\Omega$

Σύστημα με αγνώστους I_{E1}, I_3 ($B = 200$)

Από το σύστημα

$I_{E1} = 0,96 mA$ Ρεύματα Q1

και $I_3 = 0,243 mA$

προφανώς $I_{B1} = \frac{I_{E1}}{201} \Rightarrow I_{B1} = 0,0047 mA$

$I_{C1} = \frac{200}{201} I_{E1} \Rightarrow I_{C1} = 0,95 mA$

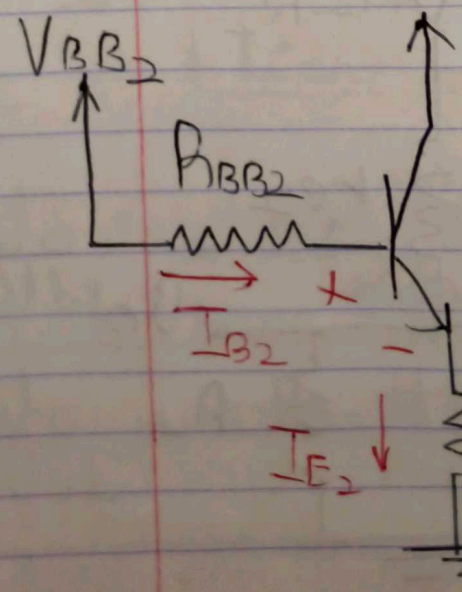
Από πριν $I_{B3} = \frac{\beta}{(\beta+1)^2} I_{E1} = \frac{200}{(201)^2} 0,96 mA$

$\Rightarrow I_{B3} = 0,0047752 mA$ Ρεύματα Q3

$I_{E3} = 201 \cdot I_{B3} = 0,955 mA$

$I_{C3} = \beta I_{B3} = 0,95 mA$

Ισοδύναμο Thevenin για να βρούμε I_{E2} (Q_2)



$R_{BB_2} = R_C = 4 k\Omega$

$V_{BB_2} = V_{CC} - R_C I_{C3}$

$\Rightarrow V_{BB_2} = 8,18 V$

ΚΤΚ:

$V_{BB_2} - V_{BE_2} = I_{B_2} R_{BB_2} + I_{E_2} R_{E_2}$

$$I_{E_2} = \frac{V_{BB_2} - V_{BE_2}}{R_{E_2} + \frac{R_{BB_2}}{\beta+1}} \Rightarrow \boxed{I_{E_2} = 4{,}11\ mA}$$

Χαρακτηριστικά Τ-μοντέλων

$$r_{e1} = \frac{V_T}{I_{E1}} = \frac{25}{0{,}96} \simeq 26\,\Omega$$

$$r_{e_2} = \frac{V_T}{I_{E_2}} = \frac{25}{4{,}11} \simeq 6\,\Omega$$

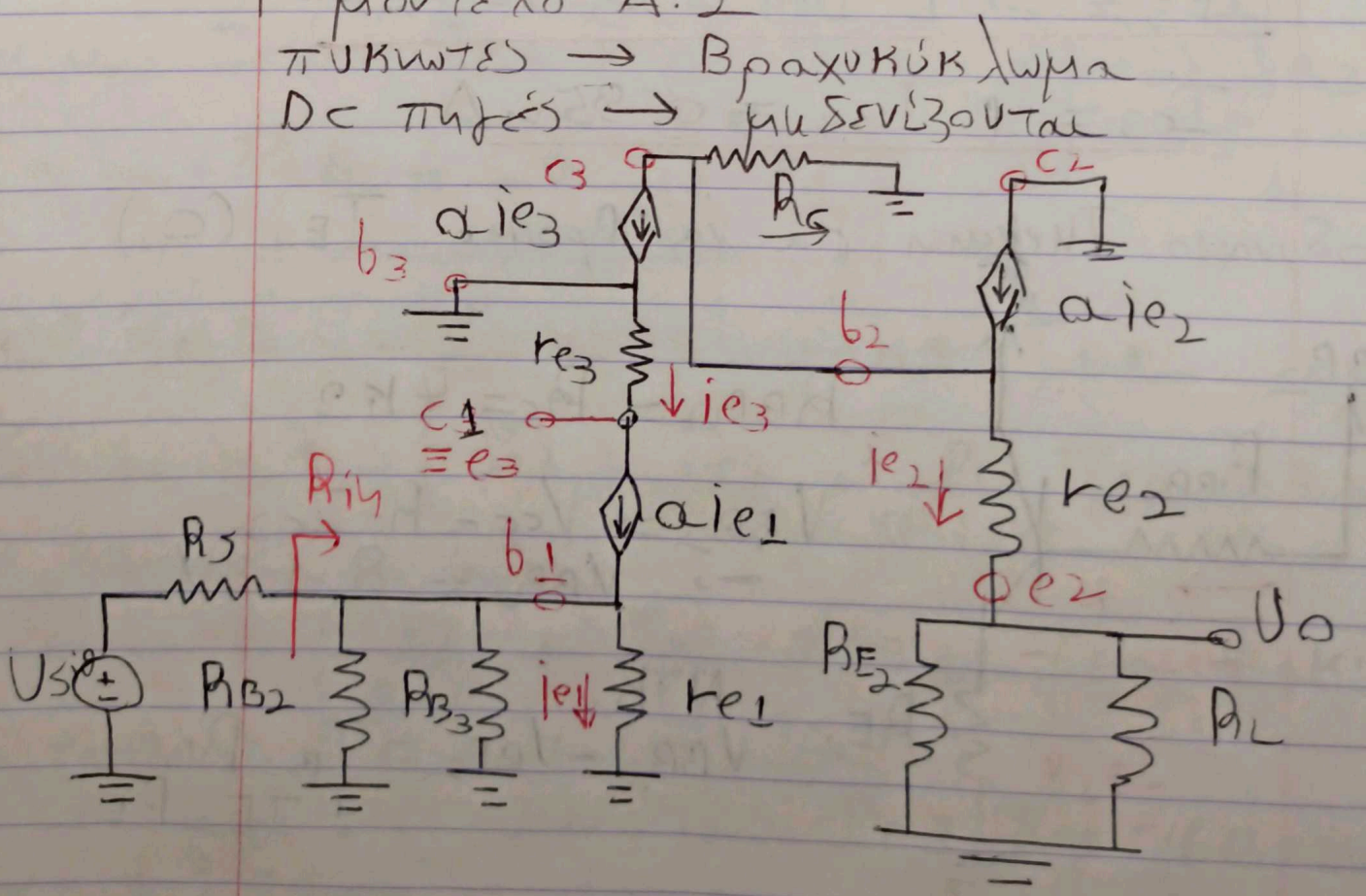
$$r_{e3} = \frac{V_T}{I_{E3}} = \frac{25}{0{,}955} \simeq 26\,\Omega$$

Α) Ac Ανάλυση

Τ-μοντέλο Α.Σ

πυκνωτές → Βραχυκύκλωμα

Dc πηγές → μηδενίζονται



~~$V_{b1} = i_{e2}(R_{E2}$~~

$$\boxed{\begin{aligned} V_o &= i_{e2}(R_{E2} \| R_L) \quad (1) \\ V_{b1} &= i_{e1} r_{e1} \quad (2) \end{aligned}}$$

ΝΡΚ $i_{b2} = -a i_{e3} - i_{Rc} = -a i_{e3} - \frac{V_{b2}}{R_c}$

$\Rightarrow V_{b2} = i_{e2}(r_{e2} + R_{E2} \| R_L)$

Οπότε $i_{b2} = -a i_{e3} - \frac{i_{e2}}{R_c}(r_{e2} + R_{E2} \| R_L)$ $\Big| \rightarrow$

αλλά $i_{e3} = a i_{e1}$, $i_{b2} = \frac{i_{e2}}{\beta+1}$

$$\frac{i_{e2}}{\beta+1} + \frac{i_{e2}}{R_c}(r_{e2} + R_{E2} \| R_L) = -a^2 i_{e3} \quad (-)$$

$$i_{e2}\left(\frac{1}{\beta+1} + \frac{r_{e2} + R_{E2} \| R_L}{R_c}\right) = -a^2 i_{e1}$$

$$\Rightarrow \boxed{\frac{i_{e2}}{i_{e1}} = \frac{-a^2 R_c(\beta+1)}{R_c + (\beta+1)(r_{e2} + R_{E2} \| R_L)}} \quad (3)$$

$$\frac{V_o}{V_{b1}} = \frac{R_{E2} \| R_L}{r_{e1}} \frac{i_{e2}}{i_{e1}} \Rightarrow$$

$$\frac{V_o}{V_{b1}} = \frac{R_{E2} \| R_L}{r_{e1}} \frac{-a^2 R_c(\beta+1)}{R_c + (\beta+1)(r_{e2} + R_{E2} \| R_L)} \quad (4)$$

Από διαίρεση τάσης $\frac{V_{sig}}{V_{b1}} = \frac{R_S + R_{B1} // R_{B2} // r_{e1}}{R_{B1} // R_{B2} // r_{e1}}$

Από (4), (5) ⇒

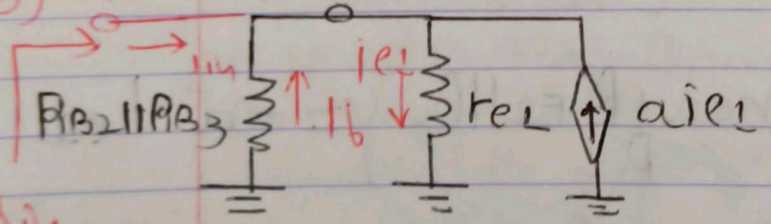
$$\frac{V_o}{V_{sig}} = \frac{V_o}{V_{b2}} \frac{V_{b1}}{V_{sig}} =$$

$$= \frac{R_{E2} // R_L}{r_{e2}} \frac{-\alpha^2 R_C (\beta+1)}{R_C + (\beta+1)(r_{e2} + R_{E2} // R_L)} \cdot \frac{R_{B1} // R_{B2} // r_{e1}}{R_S + R_{B1} // R_{B2} // r_{e1}}$$

Κέρδος τάσης

$$\boxed{\frac{V_o}{V_{sig}} \simeq -104 V}$$

B) V_{in} i_b V_{in}



R_{in}

$$R_{in} = \frac{V_{in}}{i_{in}} = \frac{V_b}{i_b - i_{e1}}$$

$$\frac{i_{in}}{V_{in}} \neq \frac{i_b}{(R_{B2} // R_{B3})\, i_b} + \frac{i_{e1}}{}$$

$$i_{in} = + i_{R_{B2} // R_{B3}} + i_{b1} \Rightarrow$$

$$V_{in} = (R_{B2} // R_{B3}) \cdot i_{R_{B2} // R_{B3}} = r_{e1} i_{e1} \Rightarrow$$

$$= r_{e1} (\beta+1) i_{b1}$$

$$\frac{1}{R_{in}} = \frac{I_{in}}{V_{in}} = \frac{I_{R_{B2}\|R_{B3}}}{I_{R_{B2}\|R_{B3}} \cdot R_{B2}\|R_{B3}} + \frac{i_{b1}}{(\beta+1) r_{e1} i_{b1}}$$

$$\Rightarrow \frac{1}{R_{in}} = \frac{1}{R_{B2}\|R_{B3}} + \frac{1}{(\beta+1) r_{e1}}$$

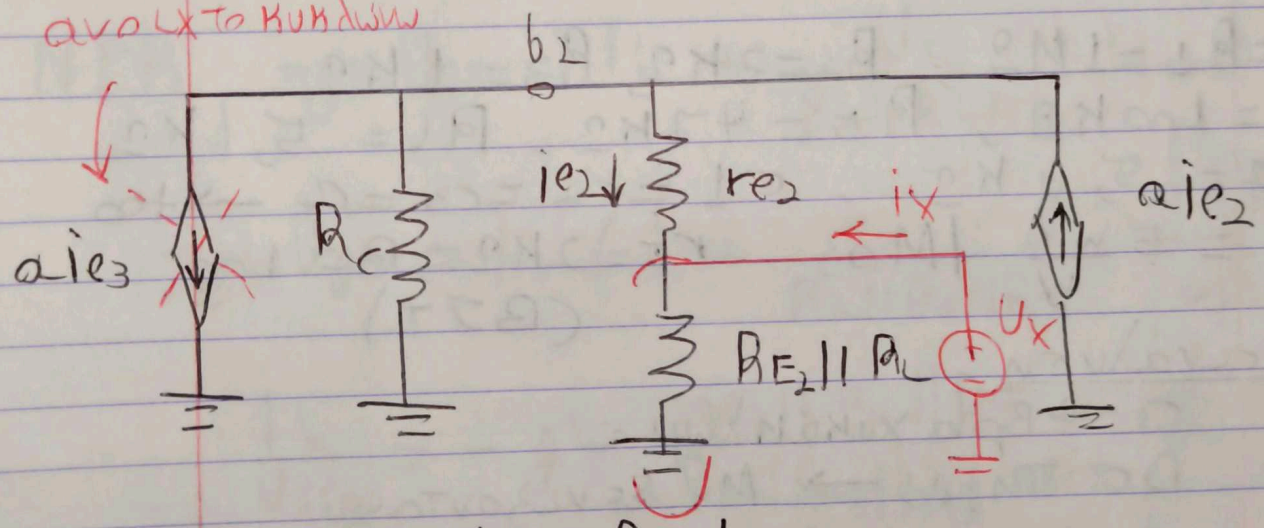
$$\Rightarrow \boxed{R_{in} = (R_{B_2} \| R_{B_3}) \| (\beta+1) r_{e1}}$$

$$\boxed{R_{in} \simeq 9,9\,k\Omega}$$

Γ) Εύρεση R_{out}

Μηδενίζω $V_{sig} = 0$

Τοποθετούμε πηγή τάσης V_x στην έξοδο



~~$\frac{V_x}{I_x} = r_{e2} I_x + R_c I_x$~~

$$V_x = -i_{e2} r_{e2} - i_{b2} R_c \Big| \Rightarrow$$
$$i_x = -i_{e2}$$

- $V_{sig} = 0 \Rightarrow V_{b1} = 0 \Rightarrow i_{e1} = 0$
  $\Rightarrow$ όμως $i_{e3} = \alpha i_{e1} = 0$
  Άρα $\alpha i_{e3} = 0$ (ανοιχτοκύκλωμα)

$$I_{R_C} = -i_{b2}$$

$$\frac{V_x}{I_x} = \frac{-i_{e2} r_{e2}}{-i_{e2}} - \frac{i_{e2}}{\beta+1} \frac{R_C}{-i_{e2}}$$

$$\frac{V_x}{I_x} = r_{e2} + \frac{R_C}{\beta+1}$$

$$R_{out} = (R_{E2} \| R_L) \| \left(r_{e2} + \frac{R_C}{\beta+1} \right)$$

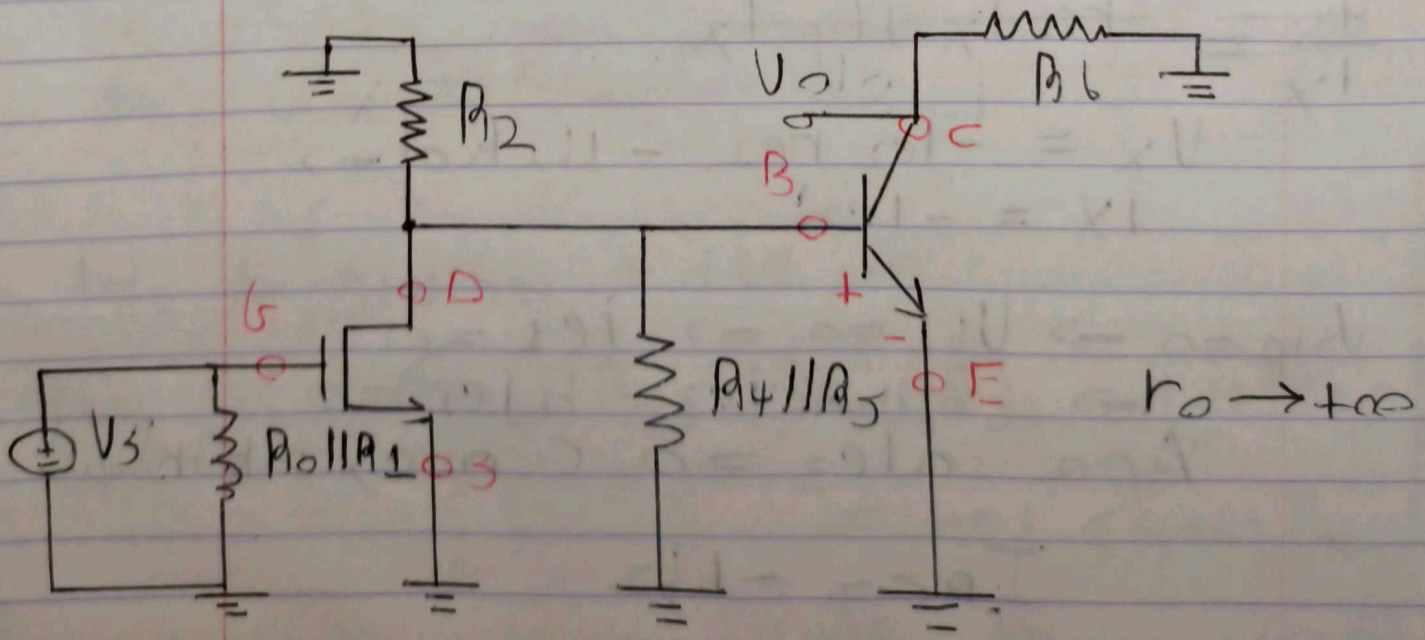
$$R_{out} \simeq 25\,K\Omega$$

Άσκηση 7

$R_0 = R_1 = 1M\Omega$, $R_2 = 3K\Omega$, $R_3 = 1K\Omega$
$R_4 = 100K\Omega$, $R_5 = 47K\Omega$, $R_6 = 5,6K\Omega$
$R_7 = 5,6K\Omega$, $C_1 = C_2 = C_3 = C_4 \to +\infty$
$g_m = 5\frac{mA}{V}$ / MOS $r_\pi = 2K\Omega$, $\beta = 100$ (BJT)

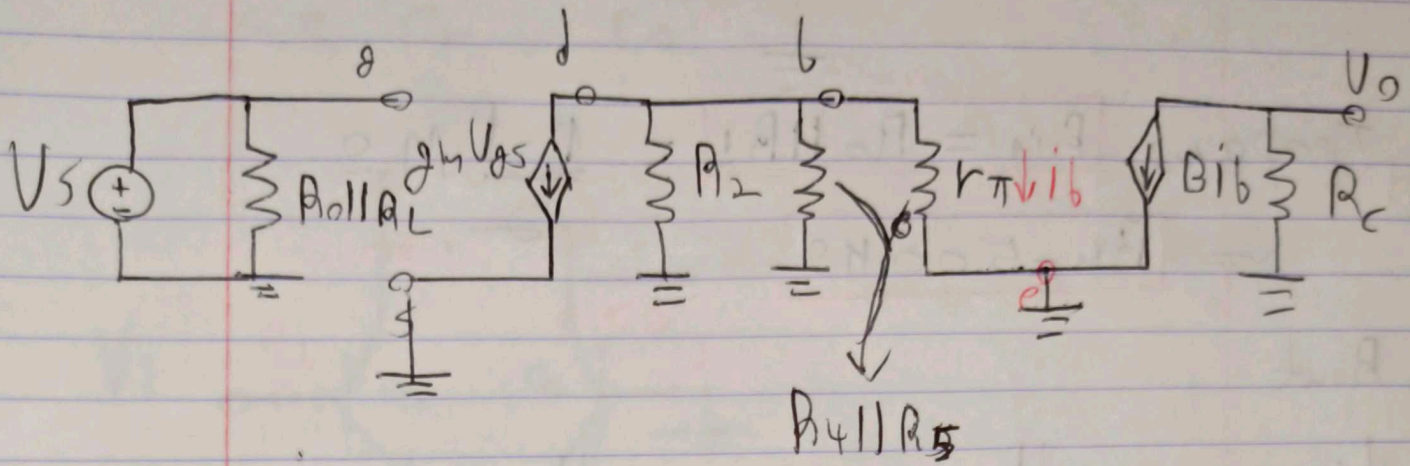
Ac ανάλυση

C → βραχυκύκλωμα
DC πηγές → μη δεν λέγονται



Αντικαθιστώντας με το ισοδύναμο π-μοντέλο

$!R_c = R_b!$



$$V_o = -\beta i_b R_c \quad (1)$$

$$V_b = r_\pi i_b$$

ΝΡΚ $\quad -g_m V_{gs} = i_b + \frac{V_b}{R_2 \| R_4 \| R_5}$ $\iff$

$$V_{sig} = V_{gs}$$

$$-g_m V_{gs} = i_b \left(1 + \frac{r_\pi}{R_2 \| R_4 \| R_5}\right) \iff \text{αφού } V_s = 0$$

$$\frac{i_b}{V_{sig}} = -g_m \frac{R_2 \| R_4 \| R_5}{R_2 \| R_4 \| R_5 + r_\pi} \quad (2)$$

↑ 2,74kΩ

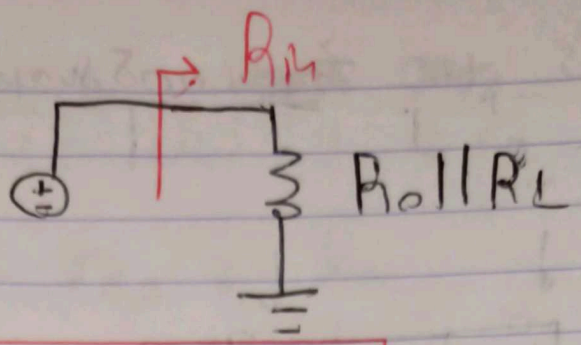
Από (1), (2)

$$\frac{V_o}{V_{sig}} = \frac{V_o}{i_b}\frac{i_b}{V_{sig}} = (-\beta R_c)(-g_m)\frac{R_2 \| R_4 \| R_5}{R_2 \| R_4 \| R_5 + r_\pi}$$

↓ 2kΩ

$$\boxed{\frac{V_o}{V_{sig}} \simeq 1618,56}$$ Κέρδος τάσης

- R_{in}



προφανώς $\boxed{R_{in} = R_o \| R_L} = \frac{1 \cdot 1}{2} M\Omega$

$\Leftrightarrow \boxed{R_{in} = 500 K\Omega}$

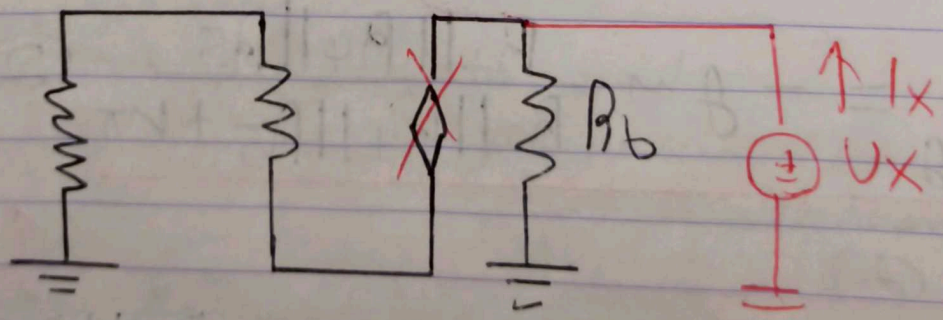
- R_{out}

$V_{sig} = 0 \Rightarrow V_{gs} = 0 \Rightarrow g_m V_{gs} = 0$

ανοιχτο κυκλωμα $g_m V_{gs}$

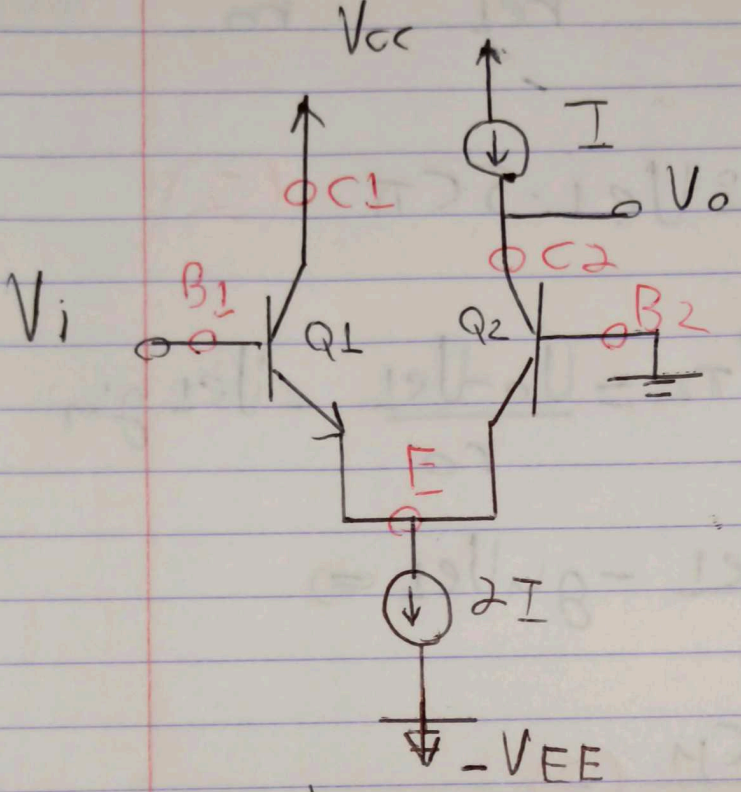
οπότε $I_b = 0 \rightarrow$ Βl b ανοιχτο κυκλώμα

οπότε $\boxed{R_{out} = R_b = 5,6 K\Omega}$

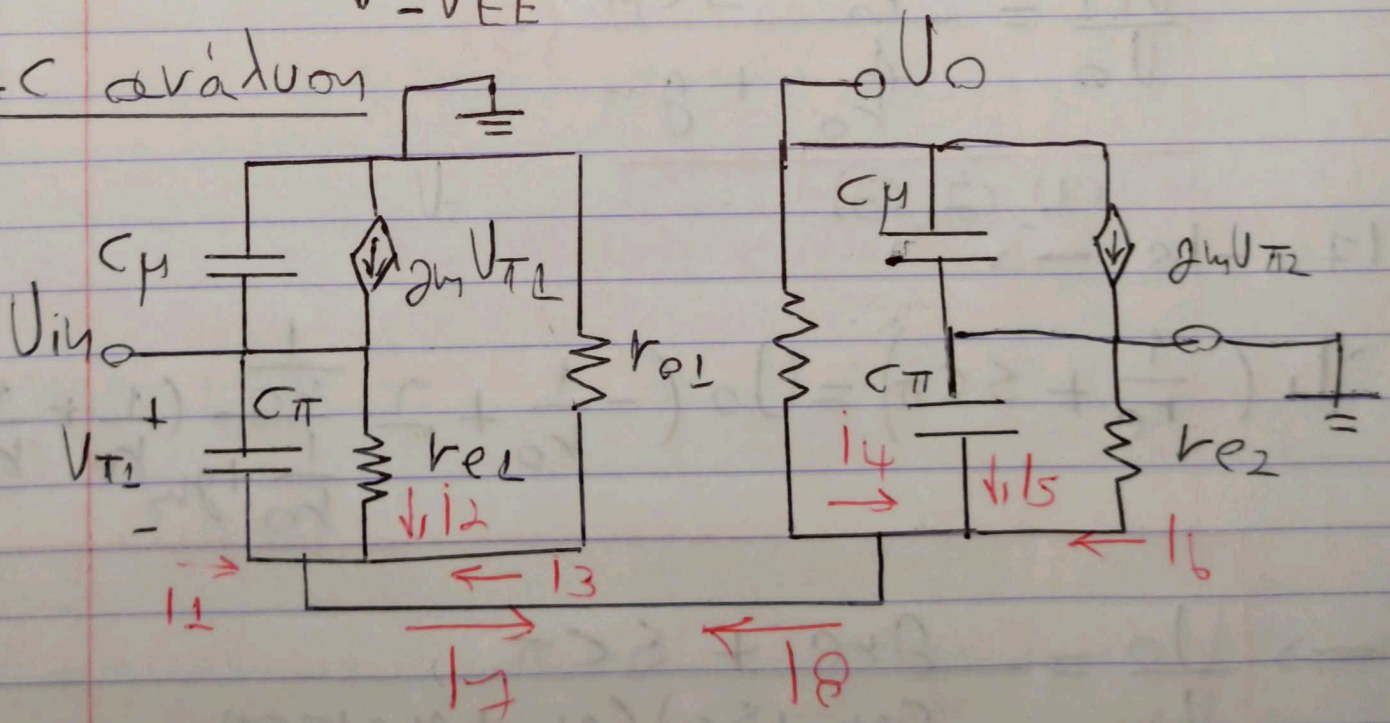


Άσκηση 8

Α) $r_{e1} = r_{e2} = r_e$, β, r_π
C_π, C_μ, r_o



AC ανάλυση



ΝΡΚ $I_7 = I_1 + I_2 + I_3$

$= (U_1 - U_{e1}) sC_\pi + (U_i - U_{e1}) \frac{1}{r_e} - U_{e1} \frac{1}{r_o}$

$\Rightarrow i_7 = (U_i - U_{e1}) sC_\pi + \frac{(U_i - U_{e1})}{r_{e1}} - \frac{U_{e1}}{r_o}$ (1)

ΝΡΚ $I_8 = I_4 + I_5 + I_6$

$= \frac{(U_o - U_{e1})}{r_o} - \frac{U_{e1}}{r_{e1}} - U_{e1} \cdot sC_\pi$ (2)

ΝΡΚ $I_{C_\mu} = I_4 + g_m V_{\pi 2} = \frac{U_o - U_{e1}}{r_o} - U_{e1} g_m$

$\Rightarrow$

$(U_o - U_o) sC_\mu = \frac{U_o - U_{e1}}{r_o} - g_m U_{e1} \Rightarrow$

$\frac{U_{e1}}{U_o} = \frac{\frac{1}{r_o} + sC_\mu}{\frac{1}{r_o} + g_m}$ (3)

(1), (2), (3)

$I_7 = -I_8 \rightarrow$

$U_i \left(\frac{1}{r_e} + sC_\pi \right) = U_o \left(-\frac{1}{r_o} + 2 \frac{\frac{1}{r_o}}{\frac{1}{r_o} + g_m} \left(\frac{1}{r_o} + \frac{1}{r_e} + sC_\mu \right) \right)$

$\Rightarrow \boxed{\frac{U_o}{U_i} = \frac{g_{re} + sC_\pi}{2 \frac{(g_{ro} + sC_\mu)(g_{ro} + g_{re} + sC_\pi)}{g_{ro} + g_m} - g_{ro}}}$

(δεν έκανε δοκ 8 τα(Β) & προσομοιώσεις)