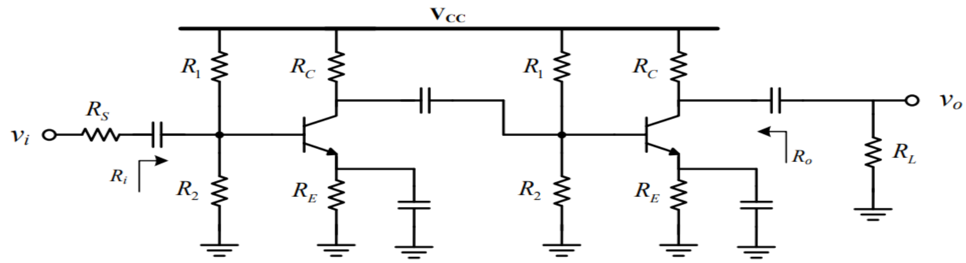
1- Calculate the voltage gain, input resistance and output resistance of the following circuit.

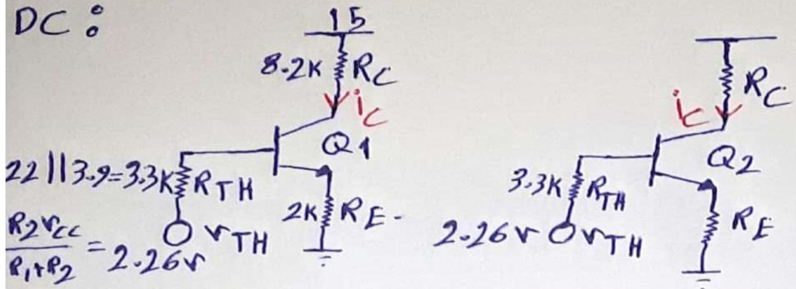


$R_1 = 22k\Omega$
$R_2 = 3.9k\Omega$
$R_C = 8.2k\Omega$
$R_E = 2k\Omega$
$R_S = 600\Omega$
$R_L = 51k\Omega$
$V_{CC} = 15V$
$\beta = 100$

DC:

-1

$V_{BE} = 0.7v$



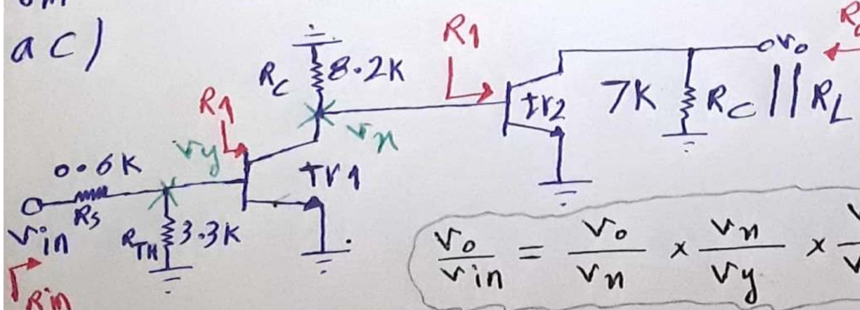
$R_E \gg \frac{R_{TH}}{\beta} \longrightarrow$ صرف نظر i_B :ا $\quad 2k\Omega \gg \frac{3.3k}{100}$ ✓

$i_C = 100 \times \frac{2.26-0.7}{200} = 0.78mA$

$v_{CE} = 15 - (R_C + R_E)\, i_C = 15 - 10.2 \times 0.78 = 7v > 0.2v$ ✓ خطی FA

$g_m = 31.2\, mS \qquad r_\pi = 3.2K\Omega \qquad r_o = \infty$

ac)



$R_{in} = $ [illegible] $+ (R_1 || R_{TH}) = 1.62K$ ✓

$R_o = R_C$ [illegible] $= 8.2k\Omega$ ✓

$\frac{v_o}{v_{in}} = \frac{v_o}{v_n} \times \frac{v_n}{v_y} \times \frac{v_y}{v_{in}}$

$R_1 = r_\pi = 3.2k\Omega$

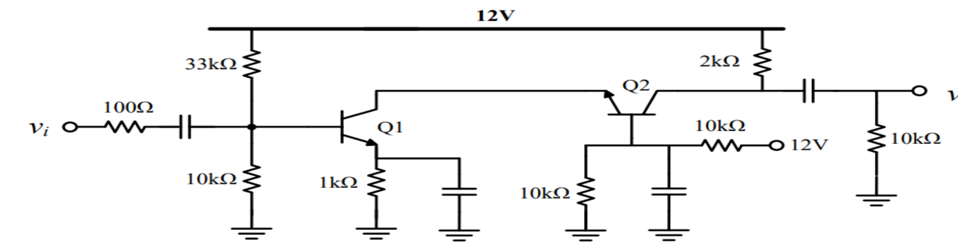
$\frac{v_o}{v_n} = -g_m R_C = -31.2 \times 7 = -218.4$ ✓

$\frac{v_n}{v_y} = -g_m (R_C || R_1) = -72$ ✓

$\frac{v_y}{v_{in}} = \frac{R_1 || R_{TH}}{(R_1 || R_{TH}) + R_S} = \frac{1.62}{1.62 + 0.6} = 0.7$ ✓

$\frac{v_o}{v_{in}} = +11007$

2- In the circuit shown below, determine the voltage gain.



$\begin{cases} Q1: \beta = 100 \\ Q2: \alpha = 1 \end{cases}$

$A_v = ?$

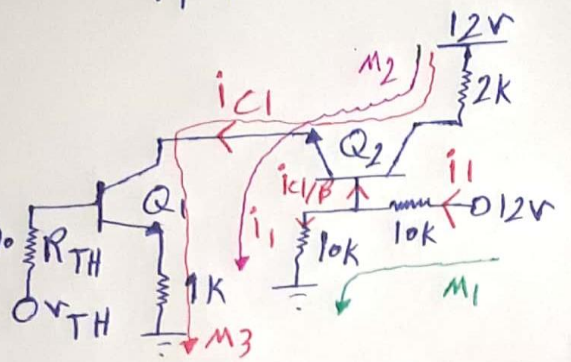
$\beta_1 = 100$

$\alpha = \frac{i_C}{i_E} = \frac{\beta}{\beta+1}$ -2

$\alpha = 1 \rightarrow \beta_2 = \beta_2 + 1 \rightarrow i_{C2} = i_{E2}$

$\beta_2 \geqslant 20$

DC)



$7.68K = 33 \| 10$

$2.8V = \frac{10 \times 12}{10+33}$

$i_{C1} = \beta_1 i_B = 100 \times \frac{2.8 - 0.7}{7.68 + 100} = 1.95\,mA$

$\beta_2 \geqslant 20 \rightarrow i_{C2} \simeq i_{E2} \rightarrow i_{C2} = i_{C1} = 1.95\,mA$

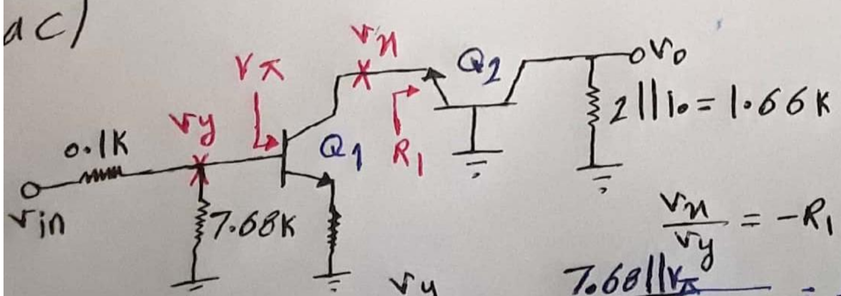
$KVL@M_1: -12 + 10i_1 + 10i_1 = 0 \rightarrow i_1 = 0.6\,mA$

$KVL@M_2: -12 + 2i_{C1} + V_{CE2} - 0.7 + 10i_1 = 0 \rightarrow V_{CE2} = 2.8V > 0.2$

$KVL@M_3: -12 + 2i_1 + V_{CE2} + V_{CE1} + i_{C1} = 0 \rightarrow V_{CE1} = 3.35 > 0.2$

$g_{m1} = g_{m2} = 78\,\frac{mA}{V}$ $\quad V_{\pi1} = 1.28\,k\Omega$

ac)



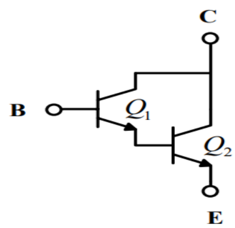
$A_v = \frac{V_o}{V_x} \times \frac{V_x}{V_y} \times \frac{V_y}{V_{in}}$

$\frac{V_o}{V_x} = +g_m R_C = 130$

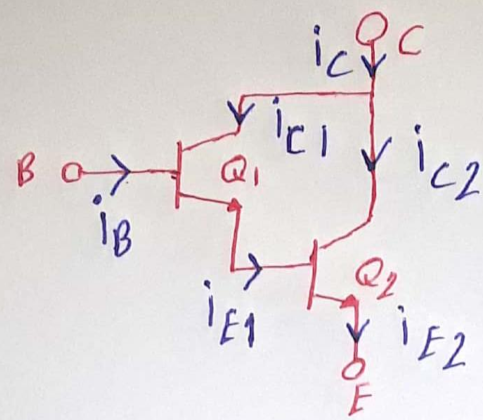
$\frac{V_x}{V_y} = -R_1 g_m = -1$

$\frac{V_y}{V_{in}} = \frac{7.68 \| r_\pi}{7.68 \| r_\pi + 0.1} = \frac{1}{1.1} = 0.9 \rightarrow \frac{V_o}{V_{in}} = -117$

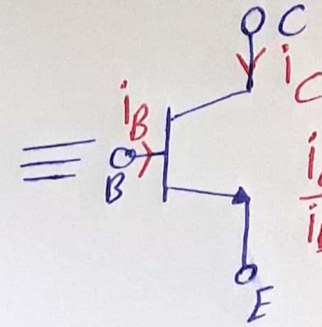
3- The following structure is known to be the "Darlington pair" configuration and is used in order to increase the β of a single transistor. This configuration can be modeled as a single NPN transistor. Determine its equivalent r_π, g_m and β.



-3



$\equiv$



$\frac{i_C}{i_B} = \beta_{new}$

$i_{C1} = \beta_1 i_B \qquad i_{E1} = (\beta_1 + 1) i_B \qquad i_{C2} = \beta_2 i_{E1}$

$i_{C2} = \beta_2 (\beta_1 + 1) i_B$

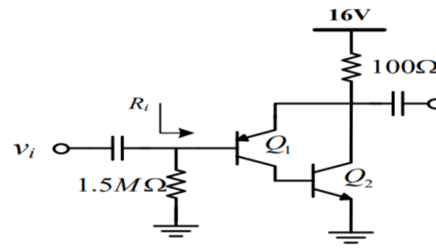
$i_C = i_{C1} + i_{C2} = \beta_1 i_B + \beta_2 (\beta_1 + 1) i_B$

$\frac{i_C}{i_B} = \beta_{new} = \frac{(\beta_1 + \beta_1\beta_2 + \beta_2)\, i_B}{i_B} \rightarrow \beta_{new} = \beta_1 + \beta_2 + \beta_1\beta_2$

$\beta_{new} \simeq \beta_1 \beta_2$

$g_{m,new} = 40 i_C \qquad r_{\pi,new} = \frac{\beta_{new}}{g_{m,new}} = \frac{\beta_1 + \beta_2 + \beta_1\beta_2}{40 i_C}$

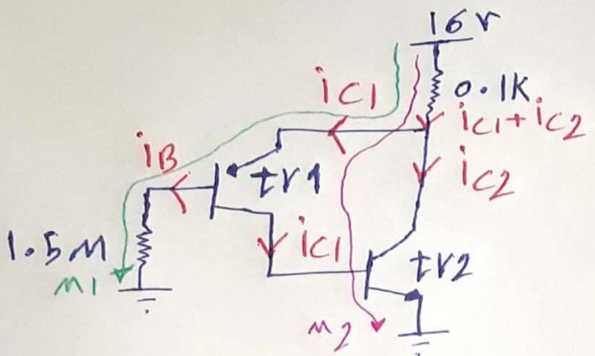
4- The following configuration is called the "Sziklai Pair" or the "Complementary Darlington pair". This configuration can be used to construct a PNP transistor with a large β. For the following circuit, determine the voltage gain and the input resistance.



$$\begin{cases}\beta_1 = 160\\ \beta_2 = 200\end{cases}$$

DC)

-4



$\beta_1 = 160$

$\beta_2 = 200$

$A_v = ?$

$R_{in} = ?$

$i_{C1} = 160 i_B \qquad i_{C2} = 200 i_{C1} = 32\times10^{3}\, i_B$

$KVL@m_1: -16 + \frac{1}{10}(i_{C2}) + 0.7 + 1500\, i_B = 0$

$i_B = 3.25\times10^{-3} \rightarrow i_{C1} + i_{C2} \simeq i_{C2} = 1.4\,mA$

$\beta_{new} = \frac{1.4}{3.25\times10^{-3}} = 32000 \qquad \beta_{new} \simeq \beta_1\beta_2$

$v_{CE2} = v_{EC1} + 0.7 \rightarrow$ همواره درناحیه فعال

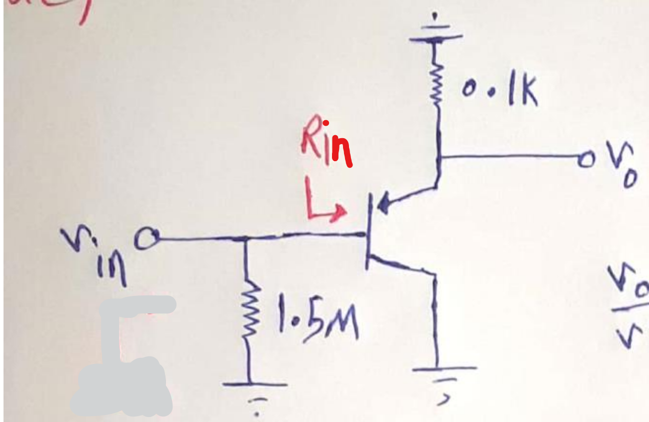
$KVL@m_2: -16 + \frac{1.4}{10} + v_{EC1} + 0.7 = 0 \rightarrow v_{EC1} = 4.9 > 0.2$

$\beta_{new} = 32000 \qquad g_{m,new} = i_{C2}\times40 = 1.40\,\frac{mA}{V}$

$r_{\pi,new} = \frac{\beta_{new}}{g_{m,new}} = 30.7\,K\Omega$

ادامه حل ص بعد

ac)

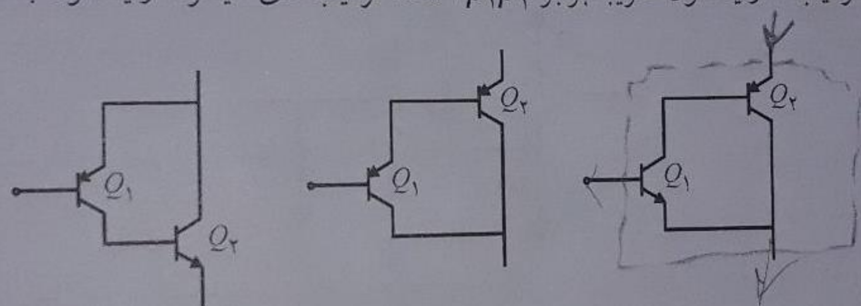


$$\frac{v_o}{v_{in}} = \frac{0.1}{0.1+\frac{1}{g_{m,new}}} \simeq 1$$

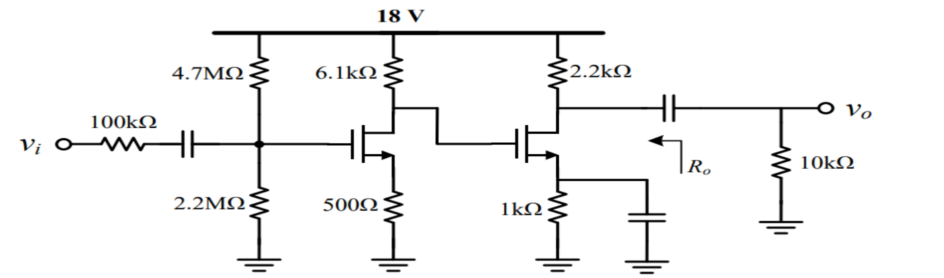
$$R_{in} = r_{\pi,new} + \beta_{new} R_E = 30.7 + 32000 \times 0.1 \simeq 3200k\Omega$$

$$\cancel{R_{in} = 1.5M \| 3.2M = 1M\Omega}$$

β کلی یک ترکیب دارلینگتون تقریباً برابر $\beta_1\beta_2$ است. ترکیب‌های دیگر دارلینگتون به صورت زیر است.

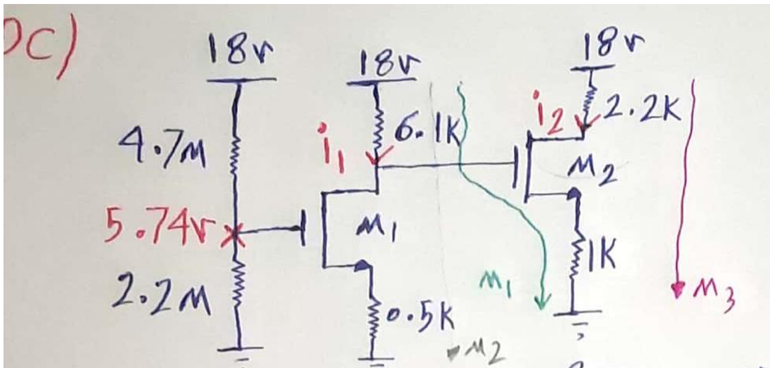


5- Determine to voltage gain and the output resistance of the following structure.



$$\begin{cases} \beta_1 = 0.5mA/V \\ \beta_2 = 0.3mA/V \\ V_{TH1} = 2V \\ V_{TH2} = 2.6V \\ r_{ds1} = 75k\Omega \\ r_{ds2} = 100k\Omega \end{cases}$$

DC)



$\beta_1 = 0.5$ $\quad r_{ds1} = 75K$ 15

$\beta_2 = 0.3$ $\quad r_{ds2} = 100K$

$v_{TH1} = 2$

$v_{TH2} = 2.6v$

$v_{GS1} = 5.74 - \frac{i_1}{2}$ $\qquad i_1 = \frac{\beta_1}{2}(v_{GS1} - v_{TH1})^2$

$v_{GS1} = 4.74$ $\qquad i_1 = \frac{1}{4}\left(5.74 - \frac{i_1}{2} - 2\right)^2$

$i_1 = \frac{1}{4}\left(3.74 - \frac{i_1}{2}\right)^2 \longrightarrow 16 i_1 = (7.48 - i_1)^2$

$i_1^2 - 31 i_1 + 56 = 0 \rightarrow i_1 = 2\,mA$

KVL @M$_1$: $-18 + 6.1 i_1 + v_{GS2} + i_2 = 0 \rightarrow v_{GS2} = 5.8 - i_2$

$i_2 = \frac{3}{20}(5.8 - i_2 - 2.6)^2 \rightarrow 20 i_2 = 3(3.2 - i_2)^2$

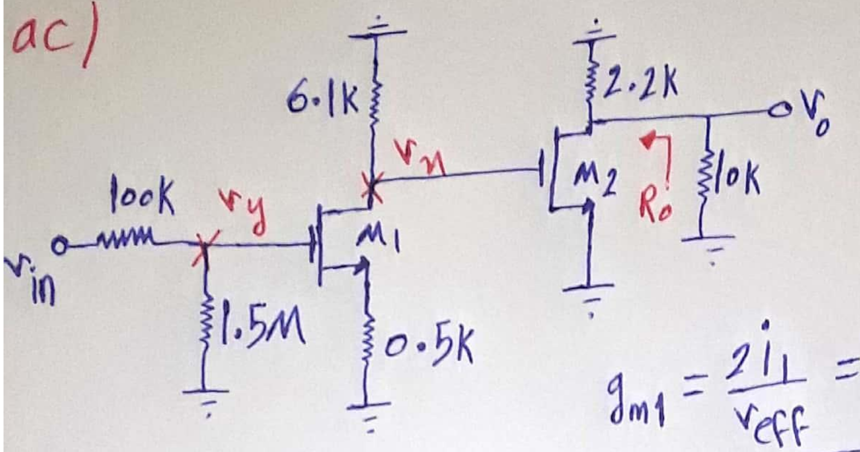
$i_2^2 - 39.2 i_2 + 30.72 = 0 \rightarrow i_2 = 0.8\,mA$

KVL @ M$_2$: $-18 + 6.1 i_1 + v_{DS1} + \frac{i_1}{2} = 0 \rightarrow v_{DS1} = 4.8 > 2.74$ ✓

KVL@M$_3$: $-18 + 2.2 i_2 + v_{DS2} + i_2 = 0 \rightarrow v_{DS2} = 15.44v$

$v_{GS2} = 5v \rightarrow v_{eff2} = 2.4v$ $\quad v_{DS2} > v_{eff2}$ ✓

ac)



$$g_{m1} = \frac{2 i_1}{v_{eff}} = \sqrt{2 \beta_1 i_1} = 1.41 mS$$

$$g_{m2} = \sqrt{2 \beta_2 i_2} = 0.7 mS$$

$$r_{ds1} = 75K \quad r_{ds2} = 100K$$

$$\frac{v_o}{v_x} \times \frac{v_x}{v_y} \times \frac{v_y}{v_{in}} = \frac{v_o}{v_{in}}$$

$$\frac{v_o}{v_x} = -g_{m2}(R_D \| r_{ds2}) = -0.7(1.8 \| 100)$$

$$\frac{v_o}{v_x} = -0.7(1.8) = -1.26 \checkmark$$

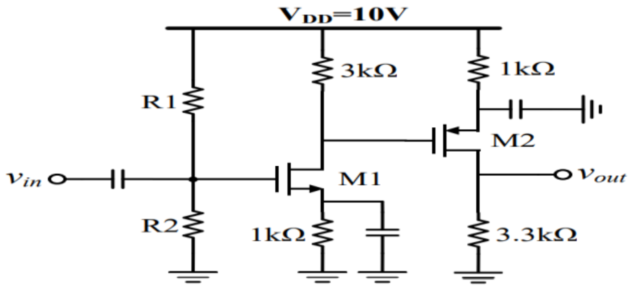
$$\frac{v_x}{v_y} = \frac{-R_D}{R_s + \frac{1}{g_{m1}}} = \frac{-6.1}{\frac{1}{2} + \frac{1}{41}} = -11.63 \checkmark$$

$$\frac{v_y}{v_{in}} = \frac{1.5M}{1.5M + 0.1M} = 0.93 \checkmark \rightarrow \boxed{\frac{v_o}{v_{in}} = +13.6}$$

$$\boxed{R_o = 2.2K \| r_{ds2} = 2.1 k\Omega}$$

6- a) Specify R_1 and R_2 so that the bias current of M1 will be equal to 1 mA.

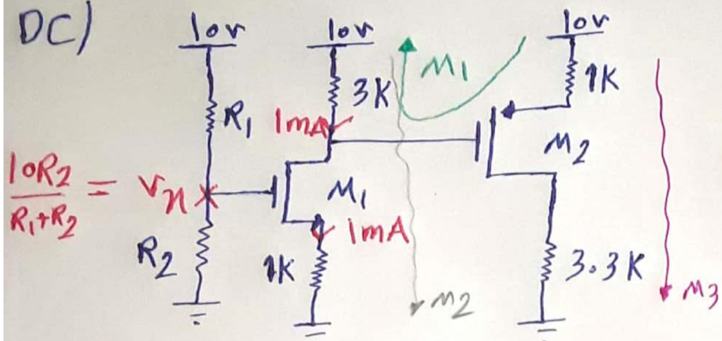
b) Calculate the voltage gain and the output resistance.



$$\begin{cases}\beta = 0.25\,\frac{mA}{V^2}\\ |V_{TH}| = 0.5V\\ \lambda = 0\end{cases}$$

1a 16

DC)



$\beta = \frac{1}{4}$

$|v_{TH}| = 0.5v$

$\lambda = 0$

$$v_{GS1} = v_{TH1} + \sqrt{\frac{2i_{D1}}{\beta}} = \frac{1}{2} + \sqrt{\frac{2}{\frac{1}{4}}} = 3.3v$$

$$v_{GS1} = v_x - 1 \Rightarrow \frac{10R_2}{R_1+R_2} - 1 = 3.3 \rightarrow \frac{10R_2}{R_1+R_2} = 4.3$$

فرض: $\boxed{R_2 = 1K}$

$$10 = 4.3R_1 + 4.3 \rightarrow \boxed{R_1 = 1.32K}$$

$$KVL@M_1: -10 + i_2 + v_{SG2} - 3 + 10 = 0 \rightarrow v_{SG2} = 3 - i_2$$

$$i_2 = \frac{1}{8}(3 - i_2 - 0.5)^2 \rightarrow 8i_2 = (-i_D + 2.5)^2$$

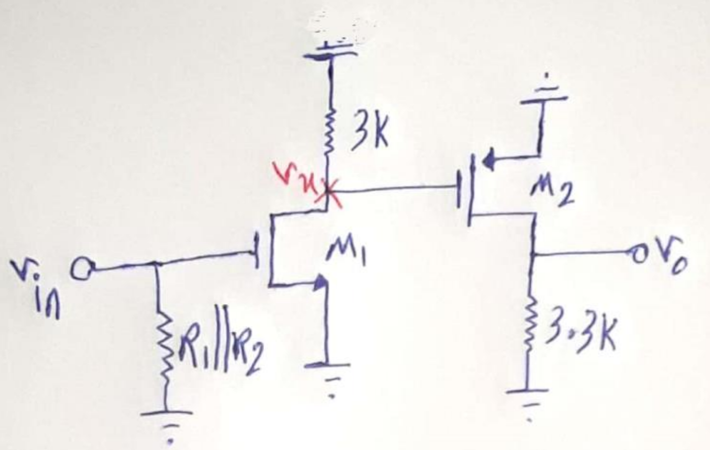
$$i_2^2 - 13i_D + 6.25 = 0 \rightarrow i_D = 0.5mA = i_2$$

$$KVL@M_2: -10 + 3 + v_{DS1} + 1 = 0 \rightarrow v_{DS1} = 6v > 3.3 - 0.5 \checkmark$$

$$KVL@M_3: -10 + 0.5 + v_{SD2} + \frac{3.3}{2} = 0 \rightarrow v_{SD2} = 7.8 > 2.5 - 0.5 \checkmark$$

$r_{ds} = \infty \qquad g_{m1} = \sqrt{2\beta i_1} = 0.7ms \qquad g_{m2} = \sqrt{2\beta i_2} = 0.5ms$

$R_o = ?$ $A_v = ?$ |b

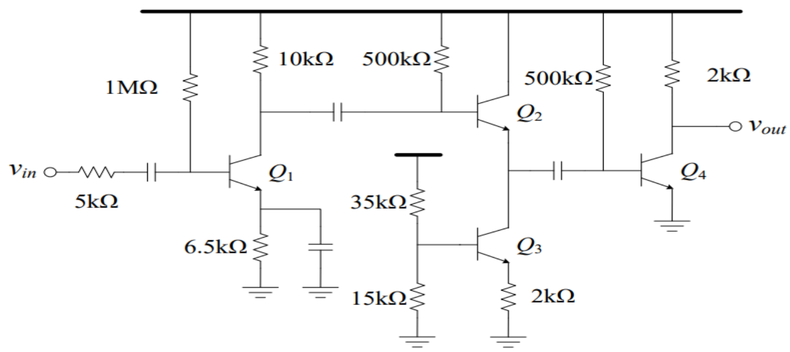


$$\frac{v_o}{v_{in}} = \frac{v_o}{v_x} \times \frac{v_x}{v_{in}} = -g_{m2} R_{D2} \times -g_{m1} R_{D1}$$

$$\frac{v_o}{v_{in}} = -\frac{1}{2} \times 3.3 \times -0.7 \times 3 = +3.46$$

$R_{out} = 3.3K\Omega$

7- Calculate the voltage gain of the structure depicted in the following figure. The transistors are in the saturation region.



$$\begin{cases} V_A = 100V \\ V_T = 25mV \\ \beta = 100 \\ I_{C1} = I_{C4} = 1mA \\ I_{C2} = 0.5mA \end{cases}$$

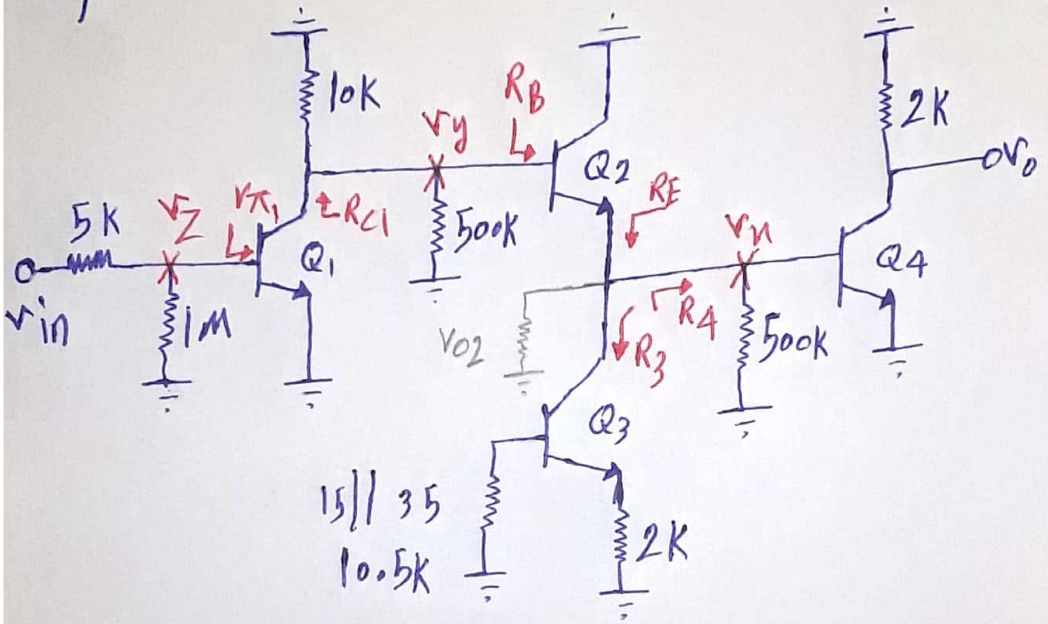
DC)

$i_{C1} = i_{C4} = 1mA \rightarrow g_{m1,4} = 40mS \rightarrow r_{\pi1,4} = 2.5k \rightarrow r_{o1,4} = 100k$ 17

$i_{C2} = i_{C3} = 0.5mA \rightarrow g_{m2,3} = 20 \rightarrow r_{\pi2,3} = 5k \rightarrow r_{o2,3} = 200k\Omega$

$A_v = ?$

ac)



$$\frac{v_o}{v_{in}} = \frac{v_o}{v_n} \times \frac{v_n}{v_y} \times \frac{v_y}{v_z} \times \frac{v_z}{v_{in}}$$

$$\frac{v_o}{v_n} = -g_{m4}(R_C || r_{o4}) = -40(2||100) = -80 \qquad \frac{v_n}{v_y} = \frac{R_E}{R_E + \frac{1}{g_{m2}}}$$

$$R_E = r_{o2} || R_3 || R_4 \qquad R_3 = r_{o3}(1 + g_{m3}(R_E || r_{\pi3}))$$

$$R_3 = 200(1 + 20(2||5)) = 5914k\Omega$$

$$R_4 = 500k || r_{\pi4} = 2.5K$$

$$R_E = 200k || 5914k || 2.5k = 2.5k\Omega \rightarrow \frac{v_n}{v_y} = \frac{2.5}{2.5 + \frac{1}{20}} = 0.98$$

$$\frac{v_y}{v_z} = -g_{m_1}(R_{C_1} \| r_{o_1})$$

$R_{C_1} = 10 \| 500k \| R_B$ $R_B = r_{\pi_2} + \beta_2 R_E$

$R_B = 5 + 100 \times 2.5 = 250k\Omega$

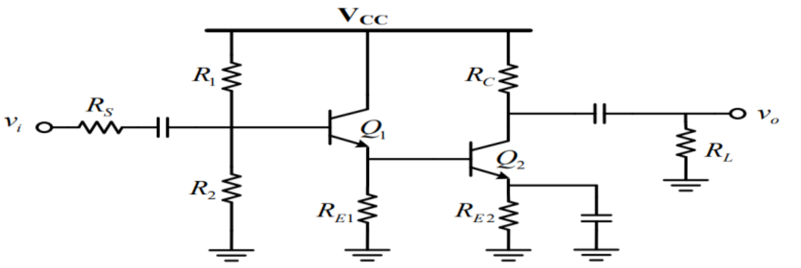
$R_{C_1} = 10 \| 250 \| 500 = 10k\Omega$

$$\frac{v_y}{v_z} = -40(10 \| 100) = \boxed{-363}$$

$$\frac{v_z}{v_{in}} = \frac{1M \| 2.5k}{1M \| 2.5k + 5k} = \frac{2.5}{2.5+5} = \boxed{0.33}$$

$$\boxed{\frac{v_o}{v_{in}} = 9391}$$

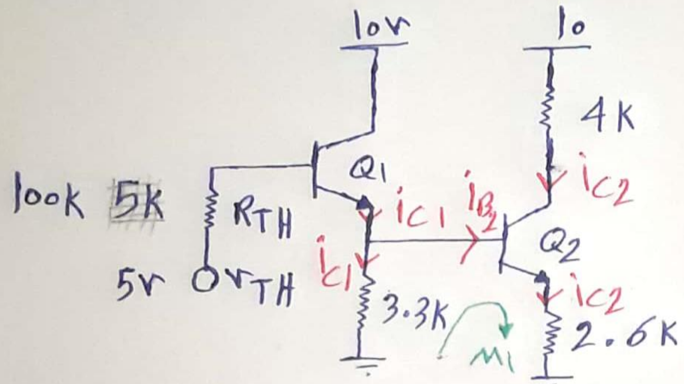
8- Calculate the voltage gain in the following circuit.



$$\begin{cases} V_{CC} = 10V \\ R_C = R_S = R_L = 4k\Omega \\ R_1 = R_2 = 200k\Omega \\ R_{E1} = 3.3k\Omega \\ R_{E2} = 2.6k\Omega \\ V_{CE,sat} = 0.2V \\ V_{BE,on} = 0.7V \\ \beta_1 = \beta_2 = 100 \end{cases}$$

DC)

$A_v = ?$ -8



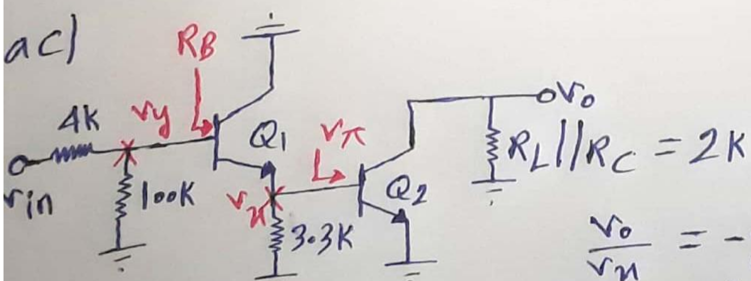
فرض : $i_{C1} >> i_{B2}$

$-5 + \frac{100\, i_{C1}}{100} + 0.7 + 3.3\, i_{C1} = 0 \rightarrow i_{C1} = 1mA$

KVL @M$_1$: $-3.3\, i_{C1} + 0.7 + 2.6\, i_{C2} = 0 \rightarrow i_{C2} = 1mA$

$i_{C1} >> i_{B2} \rightarrow 1 >> \frac{1}{100}$ ✓ $g_m = 40\,ms$ $r_\pi = 2.5K$

ac)



$$\frac{v_o}{v_{in}} = \frac{v_o}{v_x} \times \frac{v_x}{v_y} \times \frac{v_y}{v_{in}}$$

$$\frac{v_o}{v_x} = -g_m R_C = -40 \times 2 = -80$$

$R_E = 3.3 \,||\, r_\pi = 1.4K$

$$\frac{v_x}{v_y} = \frac{R_E}{R_E + \frac{1}{g_m}} = \frac{1.4}{1.4 + \frac{1}{40}} = 0.98$$

$$\frac{v_y}{v_{in}} = \frac{R_B || 100}{R_B || 100 + 4} \quad * \; R_B = r_\pi + \beta R_E = 142K \rightarrow \frac{v_y}{v_{in}} = 0.93 \rightarrow \boxed{\frac{v_o}{v_{in}} = -73}$$