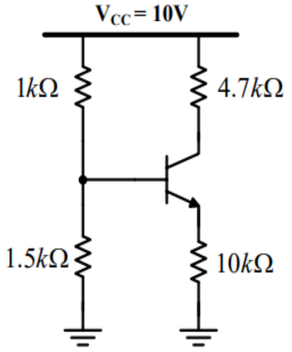
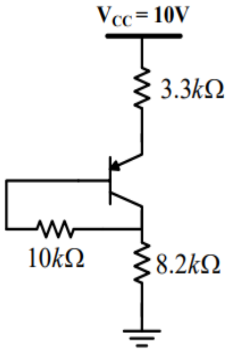
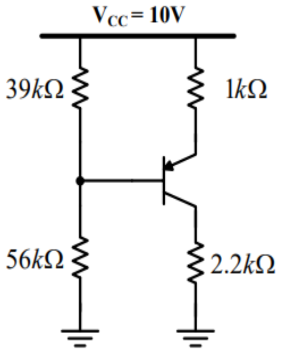
1- Determine bias points in the following circuits. In which of the following circuits, the base current can be neglected?

$$\beta=100,\ |V_{BE,ON}|=0.7V,\ |V_{CE,sat}|=0.2V$$





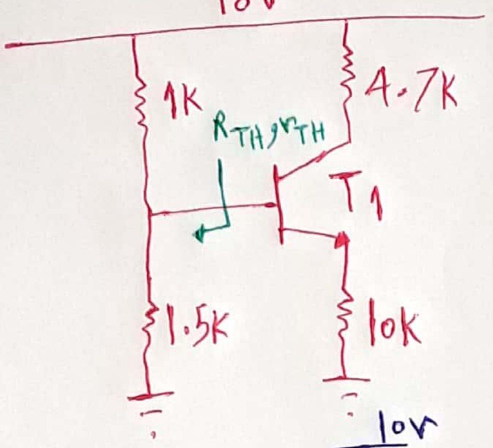


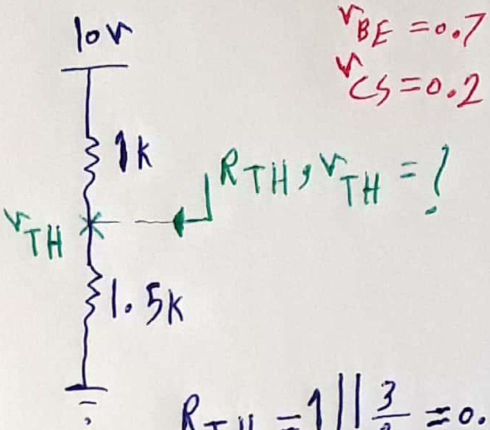
۱- نقطه کار را بدست آورید آیا i_B قابل صرف نظر است؟ $(i_C , v_{CE})=?$

$\beta = 100$

$v_{BE} = 0.7$

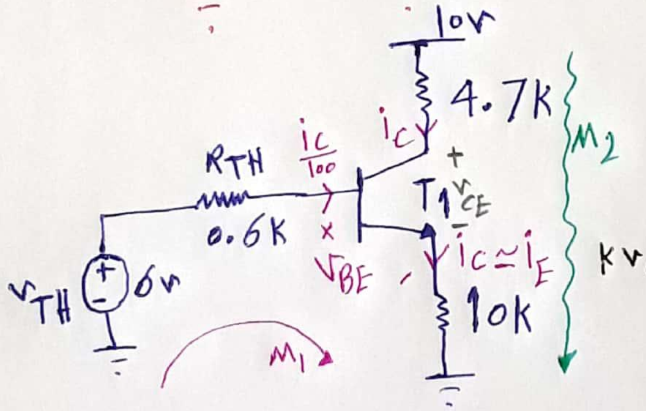
$v_{CS} = 0.2$





$$R_{TH} = 1 \| \frac{3}{2} = 0.6K$$

$$v_{TH} = \frac{\frac{3}{2} \times 10}{1+\frac{3}{2}} = 6v$$



$$\text{KVL@}M_1 : -6 + \underbrace{\frac{6}{10} \times \frac{i_C}{100}}_{\frac{6}{1000} \ll 10} + \frac{7}{10} + \underbrace{10 i_C}_{} = 0$$

از $i_B = \frac{i_C}{\beta}$ صرف نظر

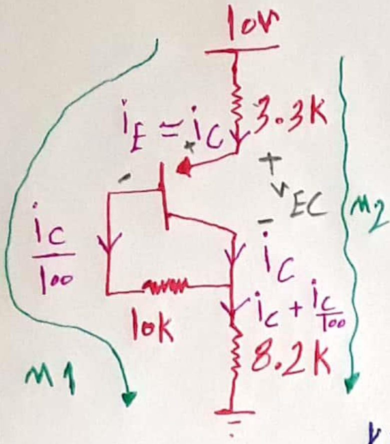
$$10 i_C = 5.3 \rightarrow i_C = 0.53mA$$

$$\text{KVL@}M_2 : v_{CE} = 10 - 10 i_C - 4.7 i_C = 10 - 14.7 i_C = 2.2 > 0.2$$

$v_{CE} > v_{CS} \rightarrow$ FAV: فعال (خطی)

می توان از i_B صرف نظر کرد.

نقطه کار : $\Big(\underset{\substack{\uparrow \\ i_C}}{0.53mA} , \underset{\substack{\uparrow \\ v_{CE}}}{2.2V}\Big)$



+11.5

$$KVL @ M_1 : -10 + 3.3 i_C + 0.7 + \frac{10 i_C}{100} + 8.2\left(i_C + \frac{i_C}{100}\right) =$$

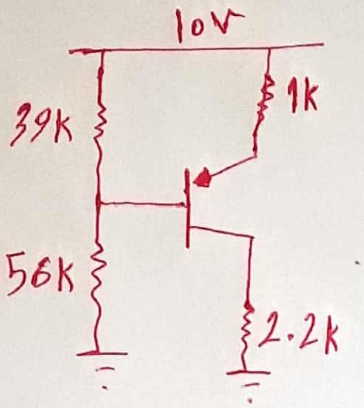
$i_B = \frac{i_C}{100}$ صرف نظر

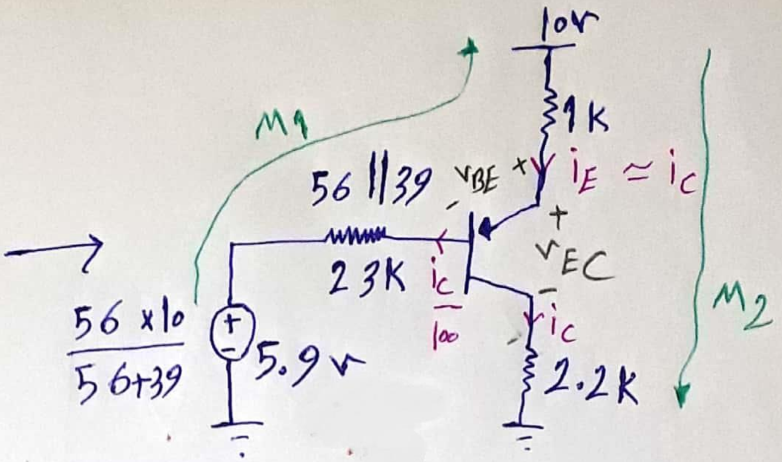
$$11.5 i_C = 9.3 \rightarrow i_C = 0.8 mA$$

$$KVL @ M_2 : v_{EC} = 10 - 11.5 i_C = 0.8v > 0.2 = v_{CS}$$

فعال : ۴۷

نقطه کار : $(i_C , v_{EC}) = (0.8mA , 0.8v)$





KVL @M₁: $-5.9 - \frac{23 i_C}{100} - 0.7 - i_C + 10 = 0$

$1.23\, i_C = 3.4 \rightarrow i_C = 2.7$

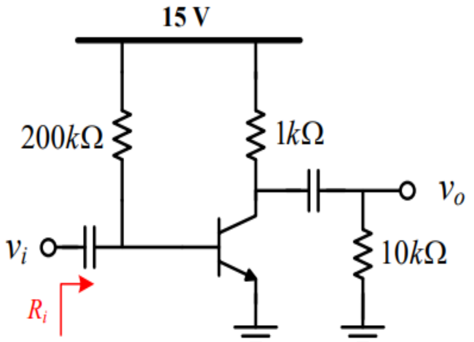
KVL @M₂: $v_{EC} = 10 - (2.2+1)\overset{2.7}{i_C} = 1.36v > 0.2 = v_{Cs}$

فعال

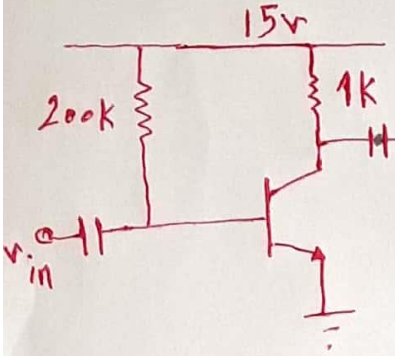
نقطه کار: $(\underset{i_C}{2.7\,mA} \,،\, \underset{v_{EC}}{1.36\,v})$

از جریان i_B
نمی توان صرف نظر کرد.

2- Calculate the input resistance (R_i) as well as the voltage gain ($A_v = v_o / v_i$) in the circuit shown below.



$$\begin{cases} V_A = \infty \\ V_T = 25mV \\ \beta = 100 \end{cases}$$



$R_{in} = ?$ $A_v = ?$ -2

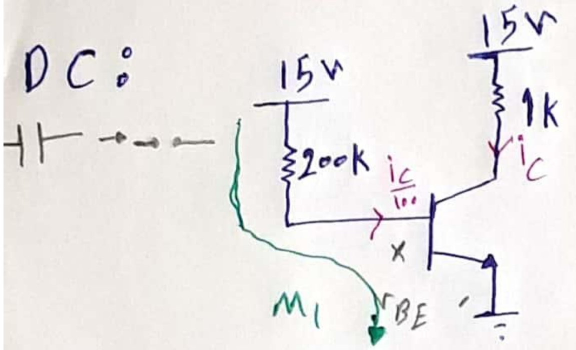
$r_A = \infty$

$v_T = 25\,mv$

$\beta = 100$

$\boxed{v_{BE} = 0.7}$

DC:



$$KVL@M_1: -15 + 200\frac{i_c}{100} + 0.7 = 0$$

$$i_C = 7.15\,mA$$

$$v_{CE} = 15 - i_C = 7.8v > 0.2v$$

FA: خطی

نقطه کار Q, $\left|\begin{matrix} 7.15mA \\ 7.8v \end{matrix}\right.$

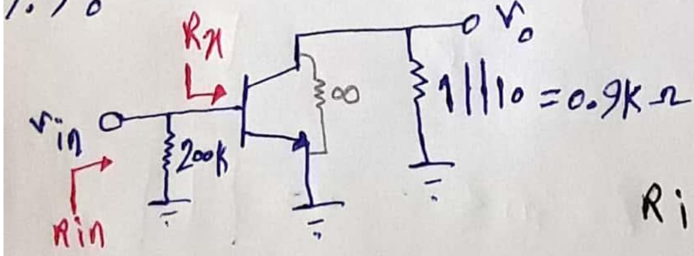
• پارامترهای

• سیگنال کوچک

$$g_m = \frac{i_c}{v_T} \simeq 40\,i_C = 286\,ms \qquad r_\pi = \frac{\beta}{g_m} = 0.35\,k\Omega$$

$$r_o = \frac{v_A}{i_c} = \infty$$

S.S:

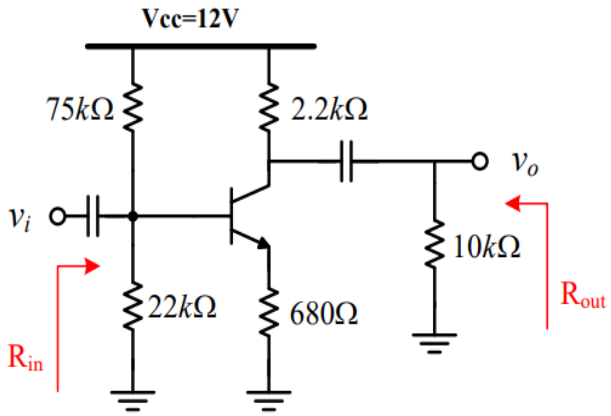


$$\frac{v_o}{v_{in}} = -g_m R_C = -257.4 \checkmark \quad \frac{v}{v}$$

$$R_{in} = 200k \,\|\, R_\pi$$

$$R_\pi = r_\pi = 0.35\,k\Omega \rightarrow R_{in} = 0.35\,k\Omega \checkmark$$

3- In the following circuit, calculate the voltage gain ($A_v = v_o / v_i$), input resistance (R_{in}) and the output resistance (R_{out}).



$$\begin{cases} V_{BE} = 0.6V \\ V_{CEsat} = 0.2V \\ V_A = 100V \\ V_T = 25mV \\ \beta = 100 \end{cases}$$

$R_{out} = ?$ $R_{in} = ?$ $A_v = ?$ -3

$v_{BE} = 0.6$

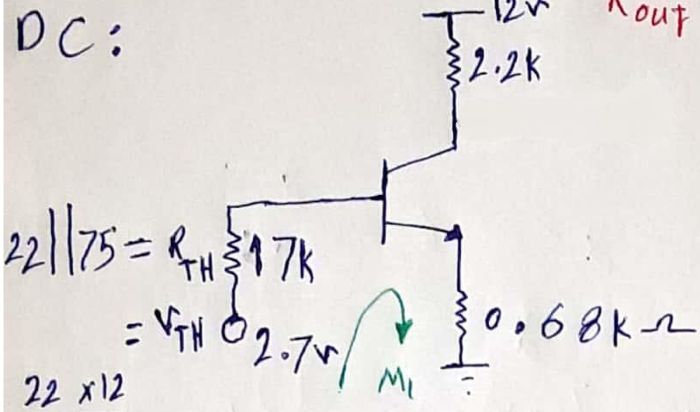
$v_{CS} = 0.2$

$v_A = 100$

$v_T = 25mv$

$\beta = 100$

DC:



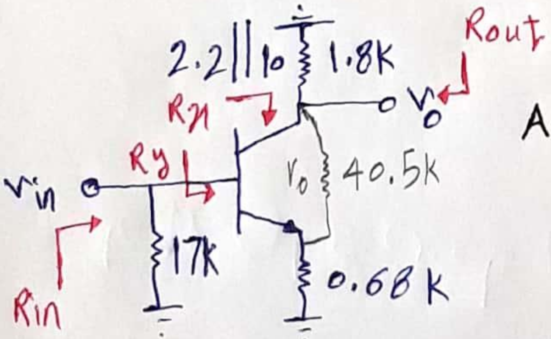
$\frac{22 \times 12}{22+75}$

$KVL @ M_1: -2.7 + \frac{17 i_C}{100} + 0.6 + 0.68 i_C = 0 \rightarrow i_C = 2.47mA$

$v_{CE} = 12 - (2.2 + 0.68) i_C = 4.8v > 0.2v = v_{CS} \rightarrow$ FV: فعال

$g_m = 98.8 mS \rightarrow r_\pi = 1k\Omega \rightarrow r_o = \frac{v_A}{i_C} = 40.5k\Omega$

S.S:



$$A_v = \frac{v_o}{v_{in}} \simeq \frac{-R_C}{R_E + \frac{1}{g_m}\left(1 + \frac{R_C}{r_o}\right)} \simeq \frac{-R_C}{R_E + \frac{1}{g_m}}$$

$R_C \ll r_o$

$$A_v \simeq \frac{-1.8}{0.68 + \frac{1}{98.8}} = -2.6 \frac{v}{v} ✓$$

$$R_x = r_o\left(1 + g_m(R_E || r_\pi)\right) = 40.5\left(1 + 98.8(0.68 || 1)\right) = 1660k$$

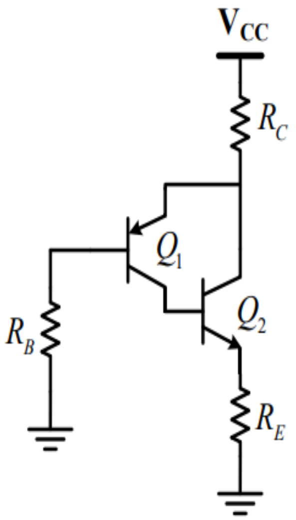
$R_{out} = 1.8k || R_x = 1.8k\Omega$ ✓ $R_{in} = 17k || R_y = 13.64k$ ✓

$$R_y \simeq r_\pi + \frac{(\beta+1) R_E r_o}{r_o + R_C + R_E} \simeq r_\pi + (\beta+1) R_E \simeq 69k$$

4- In the following circuit,

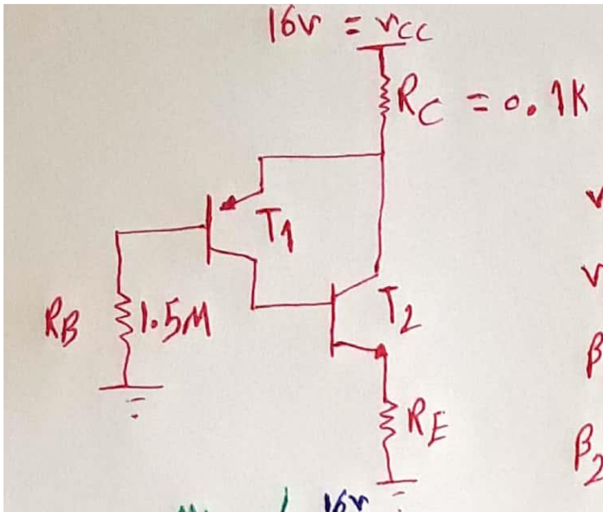
a) Determine the bias points of the transistors. Assume $R_E = 0$.

b) Calculate the maximum value of R_E for which Q_1 remains in the active region.



$$\begin{cases} V_{CC} = 16V \\ R_C = 0.1k\Omega \\ R_B = 1.5M\Omega \\ \left|V_{CE,sat}\right| = 0.2V \\ \left|V_{BE,on}\right| = 0.7V \\ \beta_1 = 160 \\ \beta_2 = 200 \end{cases}$$

4-



$v_{CS} = 0.2v$

$v_{BE} = 0.7v$

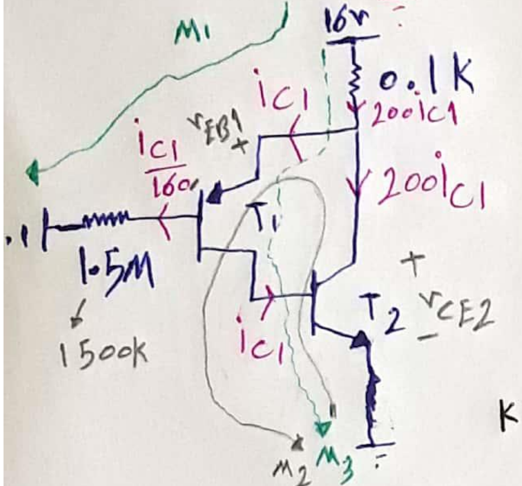
$\beta_1 = 160$

$\beta_2 = 200$

1a) i_{c1} و v_{CE1} = ?

i_2 و v_{CE2} = ?

$R_E = 0$



$$KVL@M_1: -16 + \frac{1}{10} \times 200 i_{C1} + 0.7 + \frac{1500 i_{C1}}{160} = 0$$

$$29.4\, i_{C1} = 15.3 \rightarrow i_{C1} = 0.52mA$$

$$i_{C2} = 200\, i_{C1} = 104mA$$

$$KVL@M_2: v_{CE2} = v_{EC1} + 0.7$$

T_2 همواره در ناحیه خطی است زیرا همواره $v_{CE2} > 0.9v$

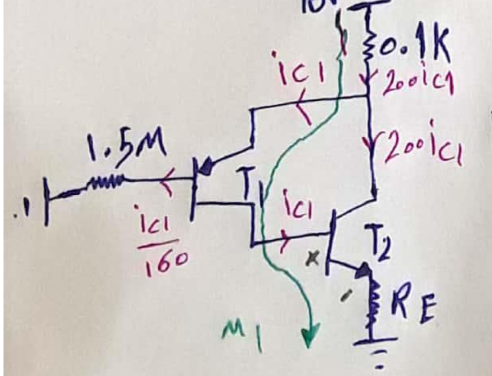
T_2: همواره در ناحیه خطی

$$KVL@M_3: -16 + \frac{1}{10} \times 200 \cdot i_{C1} + v_{EC1} + 0.7 = 0 \rightarrow$$

$v_{EC1} = 4.9v \rightarrow$ T_1: در ناحیه خطی

1b) $R_{E,max}$ = ? تا Q_1 در ناحیه خطی باقی بماند.

با توجه به قسمت 1a): $i_{C1} = 0.52$



$$KVL@M_1: -16 + \frac{200\, i_C}{10} + v_{EC1} + 0.7 + 200 R\, i_{EC_1} =$$

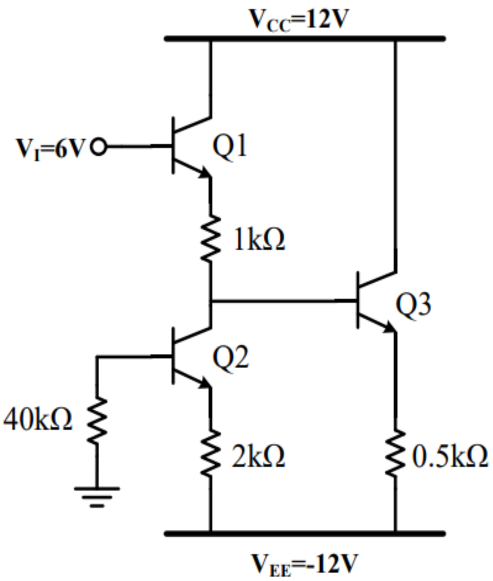
$$104 R_E = 4.9 - v_{EC1} \longrightarrow$$

$$v_{EC1,min} = v_{CS}$$

$$104 R_{E,max} = 4.9 - v_{CE1,min}$$

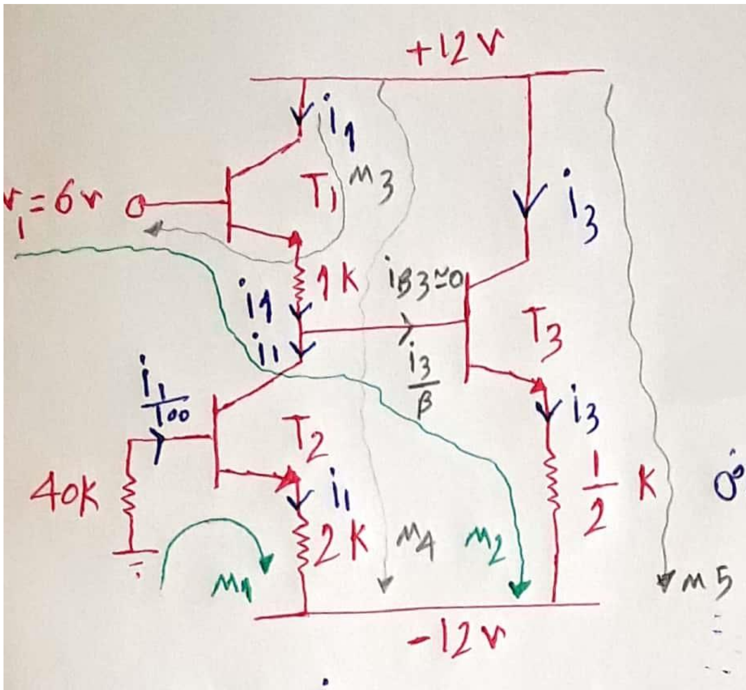
$$R_{E,max} = \frac{4.9 - 0.2}{104} = 45.2\Omega$$

5- In the circuit shown below, the transistors are the same. Determine the bias points.



$$\begin{cases}\beta = 100\\ V_{BE,ON} = 0.6V\end{cases}$$

15) i_C و v_{CE} = ؟



$\beta = 100$

$v_{BE} = 0.6$

فرض: $\frac{i_3}{\beta} << i_1 \to \boxed{i_{B3} \simeq 0}$

KVL@m1: $\frac{40 i_1}{100} + 0.6 + 2 i_1 - 12 = 0 \to i_1 = 4.75\text{mA}$ ✓

KVL@m2: $-6 + 0.6 + 1K i_1 + 0.6 + \frac{i_3}{2} - 12 = 0 \to$

$\frac{i_3}{2} = 12 \to i_3 = 24\text{ mA}$ ✓

$\frac{i_3}{\beta} = \frac{24}{100} << i_1 = 4.75 \to$ فرض صحیح

KVL@m3: $-12 + v_{CE1} - 0.6 + 6 = 0 \to v_{CE1} = 6.6v$ ✓

KVL@m4: $-12 + \underset{6.6}{v_{CE1}} + i_1 + v_{CE2} + 2 i_1 - 12 = 0 \to v_{CE2} = 3.15v$ ✓

KVL@m5: $-12 + v_{CE3} + \frac{i_3}{2} - 12 = 0 \to v_{CE3} = 12v$ ✓

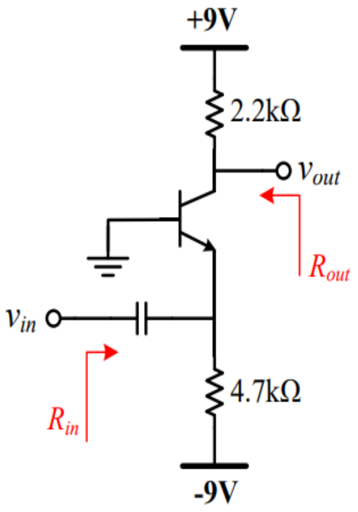
T_1 | 4.75mA → i_c ; 6.6v → v_{CE}

T_2 | 4.75mA → i_c ; 3.15v → v_{CE}

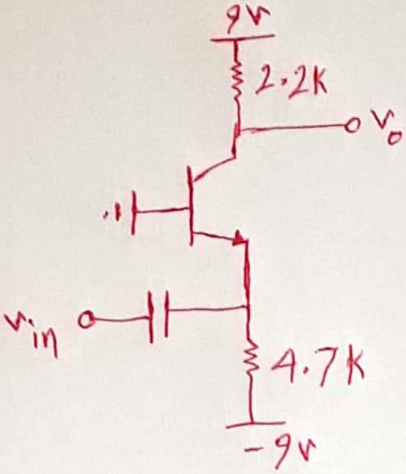
T_3 | 24mA → i_c ; 12v → v_{CE}

$v_{CE1,2,3} > 0.2 \to$ هر 3 TR در ناحیه خطی

6- Calculate the voltage gain, input resistance and output resistance of the following scheme.



$$\begin{cases} V_{BE} = 0.7V \\ V_{CEsat} = 0.2V \\ V_A = \infty \\ V_T = 25mV \\ \beta = 100 \end{cases}$$



? = Rout , Rin , Av   -6

$v_{BE} = 0.7$

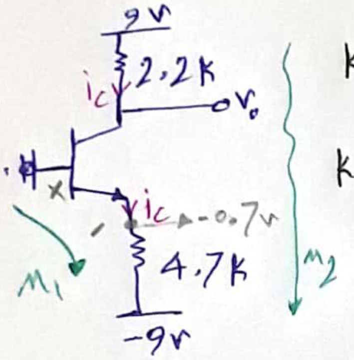
$v_{CS} = 0.2$

$v_A = \infty$

$v_T = 25mv$

$\beta = 100$

DC:



KVL@M_1: $i_C = \dfrac{9-0.7}{4.7} = 1.76mA$

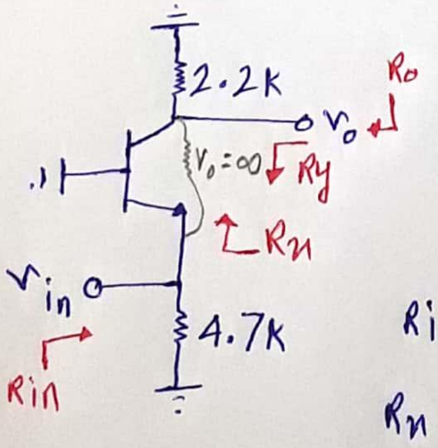
KVL@M_2: $v_{CE} = 18 - (2.2+4.7) i_C \Rightarrow$

$v_{CE} = 5.85v > 0.2v \rightarrow$ FR: فعال

$r_o = \dfrac{VA}{i_C} = \infty$ $g_m = 70.4ms$

$r_\pi = 1.4K\Omega$

ac:



$\dfrac{v_o}{v_{in}} = \dfrac{+2.2}{\frac{1}{g_m}} = 2.2 \times g_m = 154.8$ $\frac{v}{v}$ ✓

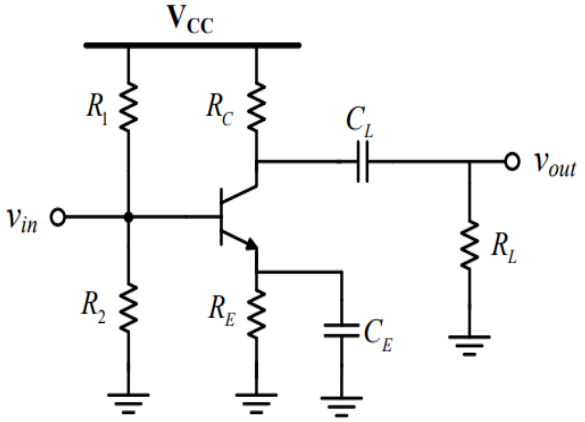
$R_{in} = 4.7 \| R_n = 14.2\Omega$ ✓

$R_n = \dfrac{1}{g_m} = 0.014K\Omega = 14.2\Omega$

$R_o = 2.2 \| R_y = 2.2K\Omega$ ✓

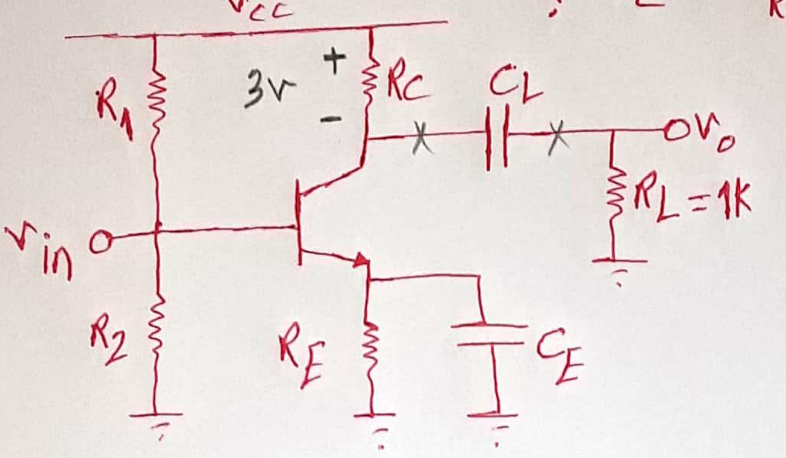
$R_y = r_o\left(1 + g_m (4.7 \| r_\pi)\right) = \infty$

7- In the following circuit, the voltage gain and the DC voltage drop on R_C is -48 V/V and 3 V, respectively. Determine R_C.



$$\begin{cases} V_{CE,sat} = 0V \\ V_T = 25mV \\ R_L = 1k\Omega \end{cases}$$

؟ $= R_C \leftarrow v_{R_C, DC} = 3v$ و $A_v = -48-7$



$v_{CE, sat} = 0v$

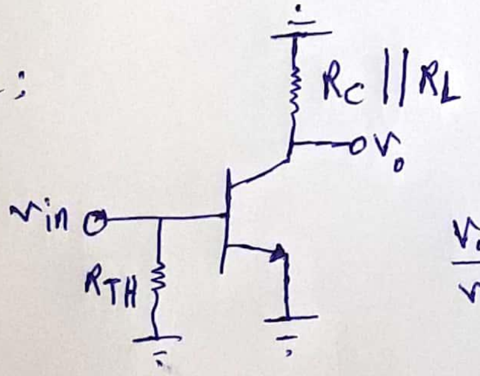
$V_T = 25mV$

$R_L = 1k\Omega$

DC : خازن $C_L \rightarrow$ اتصال باز

$$\boxed{i_c = \frac{3}{R_C}} \qquad g_m = 40 i_c = \frac{120}{R_C} \text{ ms}$$

ac:



طبق سوال 48-

$$\frac{v_o}{v_{in}} = -g_m (R_C || R_L) = A_v$$

$$48 = \frac{120}{R_C} (R_C || 1) \rightarrow$$

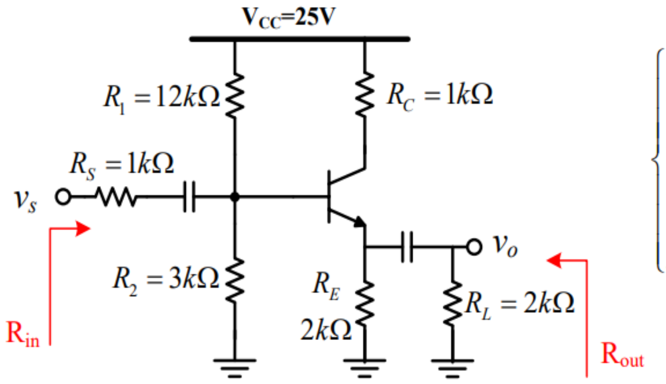
$$48 = \frac{120}{\cancel{R_C}} \left(\frac{\cancel{R_C}}{R_C + 1} \right) \rightarrow 48 R_C = 72 \rightarrow \boxed{R_C = 1.5k\Omega}$$

8- In the following circuit,

a) Calculate the voltage gain ($V_{BE,ON}$=0.7V).

b) Determine the output voltage (v_o) swing.

c) Modify R_1 in order to maximize the output voltage swing.



$$\begin{cases} V_{BE} = 0.6V \\ V_{CEsat} = 0.2V \\ V_A = \infty \\ V_T = 25mV \\ \beta = 80 \end{cases}$$

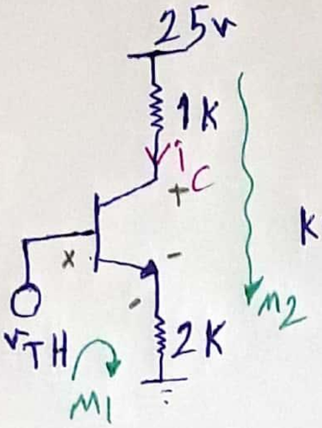
-8

$\beta = 80 \quad v_{BE} = 0.7v \quad A_v = ? \; -a$

DC:

صرف نظر از i_B

$\beta R_E >> R_{TH}$



$KVL@M_1: i_C = \frac{5-0.7}{2} = 2.1mA$

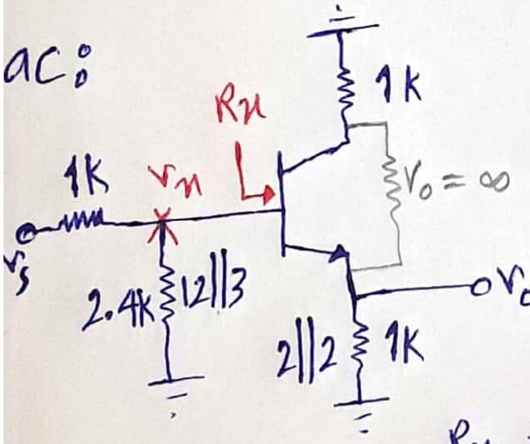
$KVL@M_2: v_{CE} = 25 - (2+1) i_C$

$v_{CE} = 18.7v > 0.2 \rightarrow tr:$ فعا

$5v = \frac{3 \times 25}{(3+12)} = v_{TH}$

$g_m = 84 \frac{mA}{v} \qquad r_\pi = \frac{\beta}{g_m} = \frac{80}{g_m} \simeq 1k\Omega \qquad r_o = \frac{v_A}{i_C} = \infty$

ac:

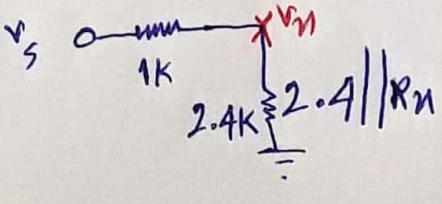


$\frac{v_o}{v_s} = \frac{v_o}{v_n} \times \frac{v_n}{v_s}$

$\frac{v_o}{v_n} = \frac{1}{1 + \frac{1}{g_m}} \simeq 1$

$R_n = r_\pi + (\beta + 1) R_E = 1 + 80 \simeq 80k\Omega$

$\frac{v_n}{v_s} = \frac{2.4}{2.4+1} = 0.7$



$\frac{v_o}{v_s} = 0.7 \times 1 = 0.7 \frac{v}{v}$ ✓

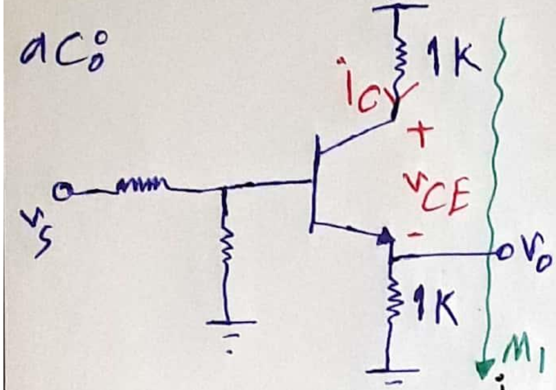
-8

swing{v_o} = ? | b

نقطة ✓, | $v_{CEQ} = 18.7v$

| $i_{CQ} = 2.1mA$

ac:

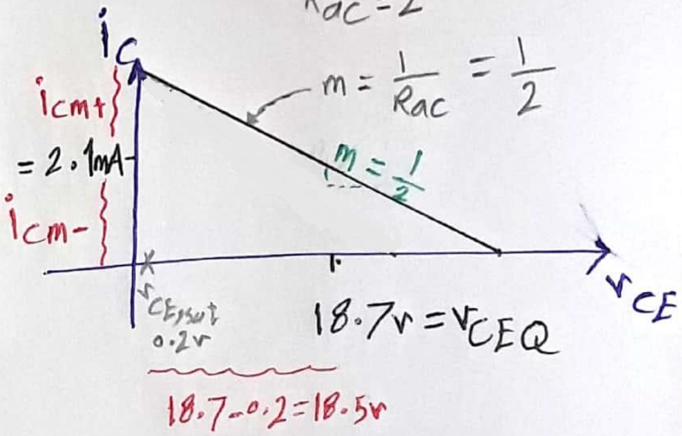


KVL@M_1 : $1i_c + v_{CE} + i_c = 0$

$v_{ce} = -2i_c$

$R_{ac} = 2$

$m = \frac{1}{R_{ac}} = \frac{1}{2}$



$i_{cm-} = i_{CQ} = 2.1$ mA

$i_{cm+} = \frac{v_{CEQ} - v_{CE,sat}}{R_{ac}} = \frac{18.7 - 0.2}{2} = 9.25$

swing{i_c} = min{i_{cm+}, i_{cm-}} = 2.1mA

$v_o = 1ki_c \rightarrow$ swing{v_o} = 1k swing{i_c} = 2.1v ✓

8- C| $R_1 = ?$ تا $swing\{v_o\}$ حداکثر شود.

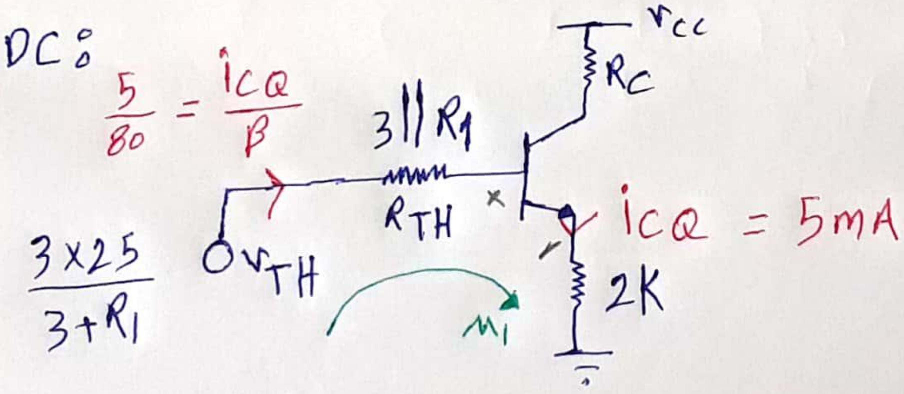
می خواهیم $swing\{v_o\}$ حداکثر شود $\longrightarrow i_{CQ} = \frac{V_{CC,eff} - V_{CE,sat}}{R_{dc} + R_{ac}}$

$R_{dc} = 3k\Omega$

$R_{ac} = 2k\Omega$

$$i_{CQ} = \frac{25 - 0.2}{3 + 2}$$

$i_{CQ} \simeq 5mA \longrightarrow$ جریان i_C در حالت DC



$R_1 \| 3 < 3K \longrightarrow \underset{80}{\beta} \underset{2K}{R_E} \gg \underset{R_{TH,max} = 3K}{R_{TH}} \longrightarrow$ جریان بیس صرف نظر

$\boxed{160K \gg 3K}$

KVL @M_1: $\frac{-75}{R_1 + 3} + 0.6 + 2 \times 5 = 0 \rightarrow 10.6 R_1 = 43.2 \rightarrow$

$\boxed{R_1 = 4k\Omega}$