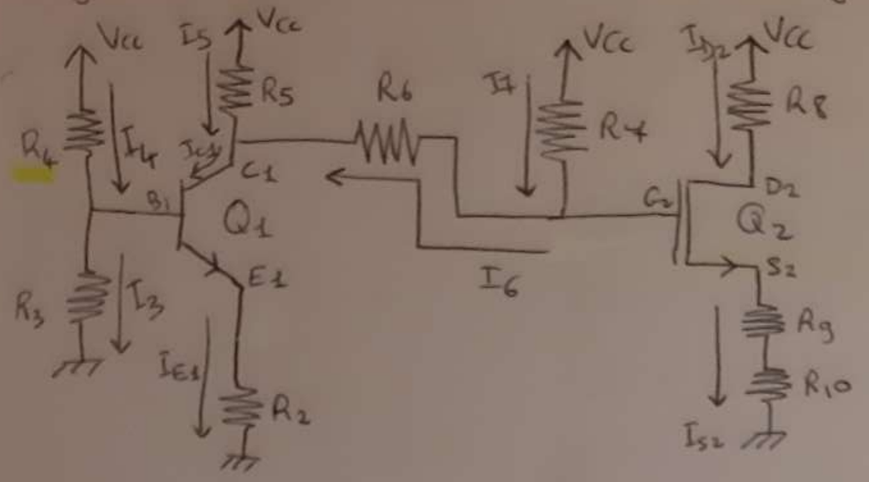
Prova Scritta del 18 Febbraio 2019

$\boxed{\text{ESERCIZIO A) 1)}}$

Disegno il circuito in continua ed assegno le correnti sui rami:



$V_{D2} = 12\,V$

$I_{D2} = \dfrac{V_{CC} - V_{D2}}{R8} = 5 \cdot 10^{-4} A$

$I_{G2} = 0 \Rightarrow I_{S2} = I_{D2}$

$V_{S2} = I_{S2} \cdot (R_9 + R_{10}) = $
$= 8\,V$

Ipotesi 1: Q_2 in zona di saturazione $\Rightarrow I_{D2} = K\,(V_{GS2} - V_T)^2$

Ovvero $V_{GS2} = V_T \pm \sqrt{\dfrac{I_{D2}}{K}}$

Dato che affinché Q_2 conduca è necessario che $V_{GS2} > V_T$,

$V_{GS_2} = V_T + \sqrt{\dfrac{I_{D_2}}{K}} = 2\,V$

Verifico l'Ipotesi 1: $V_{DS2} = V_{D2} - V_{S2} = 4\,V$, risulta quindi che

$V_{DS2} = 4\,V \geq 1\,V = V_{GS2} - V_T$. Ipotesi 1 verificata.

$V_{G2} = V_{GS2} + V_{S2} = 10\,V$

$I_7 = \dfrac{V_{CC} - V_{G2}}{R7} = 4 \cdot 10^{-4} A$

$I_6 = I_7 = 4 \cdot 10^{-4} A$

$V_{C1} = V_{G2} - I_6 R_6 = 9{,}2\,V$

$I_5 = \dfrac{V_{CC} - V_{C1}}{R_5} = 1{,}6 \cdot 10^{-3} A$

$I_{C1} = I_5 + I_6 = 2 \cdot 10^{-3} A$

Ipotesi 2: Q_1 in zona attiva diretta $\Rightarrow I_{B1} \ll I_{C1}$

$\Rightarrow I_{E1} = I_{C1} = 2\,mA$

$V_{E1} = I_{E1} \cdot R_2 = 4{,}2\,V$

$V_{CE1} = V_{C1} - V_{E1} = 5\,V$

Q_1 si trova nel punto di lavoro $I_{C1} = 2\,mA$ e $V_{CE1} = 5\,V$, per cui il costruttore fornisce i seguenti valori tabulati:

$\begin{cases} h_{FE} = 290 \\ h_{ie} = 4800\,\Omega \\ h_{fe} = 300 \end{cases}$

Secondo gli standard delle tecnologie odierne $V_{BE1} = V_\gamma = 0{,}7\ V$

$V_{B1} = V_{BE1} + V_{E1} = 4{,}9V$

$I_{B1} = \frac{I_C}{h_{FE}} = 6{,}896551 \cdot 10^{-6} A$

$I_3 = \frac{V_{B1}}{R_3} = 2 \cdot 10^{-5} A$

$I_4 = I_3 + I_{B1} = 2{,}6896551 \cdot 10^{-5} A$

$R_4 = \frac{V_{CC} - V_{B1}}{I_4} = 487051{,}29\ \Omega$

$\boxed{\text{PUNTI DI RIPOSO}}$

Q_1:

$I_{C1} = 2\ mA$

$V_{CE1} = 5\ V$

$I_{B1} = 6{,}896551 \cdot 10^{-6} A$

$h_{ie} = 4800\ \Omega$

$h_{fe} = 300$

Q_2:

$I_{D2} = 5 \cdot 10^{-4} A$

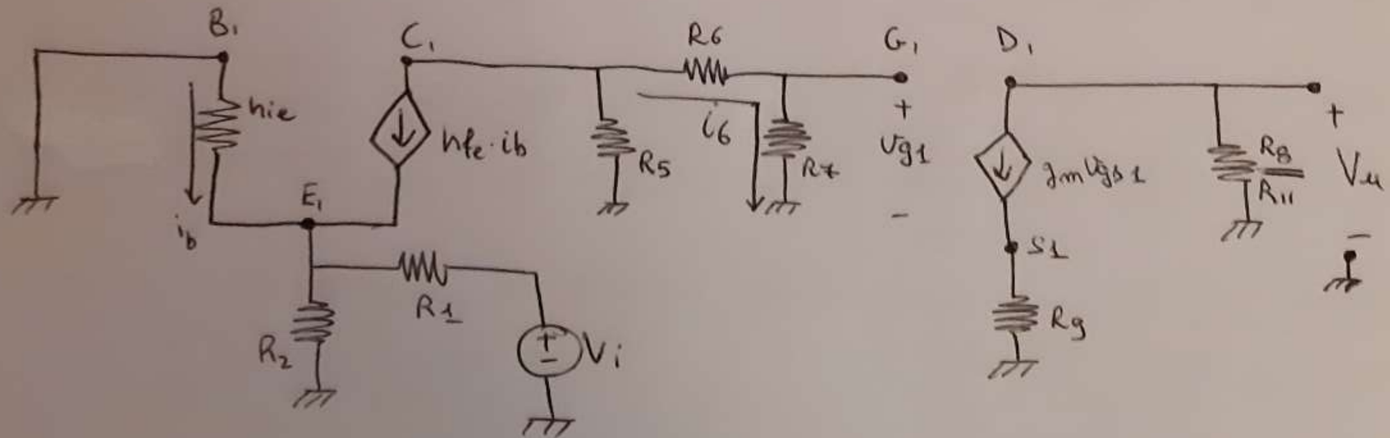
$V_{GS2} = 2V$

$V_{DS2} = 4V$

$g_m = 2 \cdot K \cdot |V_{GS2} - V_T| =$
$= 1 \cdot 10^{-3}$

$\boxed{\text{ESERCIZIO A) 2)}}$

Disegno il circuito per le variazioni:



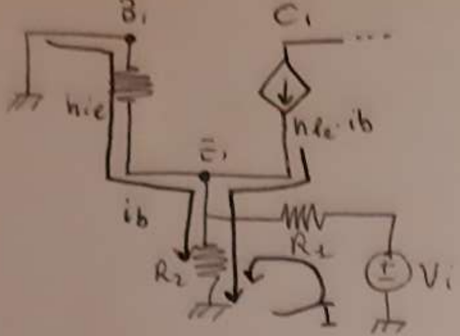
$V_u = -g_m v_{gs1} \cdot (R_8 // R_{11}) = -g_m v_{gs1} \cdot R_{eq1}$

$v_{s1} = g_m v_{gs1} \cdot R_9$

$$i_6 = -h_{fe}\cdot i_b \cdot \frac{R_5}{R_5+R_6+R_7}$$

$$v_{g1} = i_6 \cdot R_7 = -h_{fe}\cdot i_b \cdot \frac{R_5\cdot R_7}{R_5+R_6+R_7} = -h_{fe}\cdot i_b \cdot R_{eq2}$$

$$v_{gs1} = v_{g1} - v_{s1} = -h_{fe}\cdot i_b \cdot R_{eq2} - g_m v_{gs1}\cdot R_g \Rightarrow v_{gs1} = \frac{-h_{fe}\cdot i_b\cdot R_{eq2}}{1+g_m\cdot R_g}$$



Correnti di maglia:

$$\begin{cases} V_i = I\cdot R_1 + I\cdot R_2 + h_{fe}\cdot i_b\cdot R_2 + i_b\cdot R_2 \\ 0 = h_{ie}\, i_b + R_2\cdot i_b + h_{fe}\, i_b\cdot R_2 + I R_2 \end{cases}$$

$$I = \frac{-h_{ie}\cdot i_b - R_2 i_b - h_{fe} i_b\cdot R_2}{R_2} =$$

$$= -i_b \frac{\left(h_{ie} + R_2 + h_{fe}\cdot R_2\right)}{R_2} =$$

$$= -i_b\cdot R_{eq3}$$

$$V_i = I\left(R_1+R_2\right) + i_b\left(h_{fe}\cdot R_2 + R_2\right) = I\cdot R_{eq4} + i_b\cdot R_{eq5} =$$

$$= i_b\cdot R_{eq5} - i_b\cdot R_{eq3}\cdot R_{eq4} = i_b\left(R_{eq5} - R_{eq3}\cdot R_{eq4}\right) =$$

$$= i_b\cdot R_{eq6}$$

$$\frac{V_u}{V_i} = \frac{-g_m\cdot v_{gs1}\cdot R_{eq1}}{i_b\cdot R_{eq6}} = \frac{-g_m\cdot \frac{-h_{fe}\cdot \cancel{i_b}\cdot R_{eq2}}{1+g_m R_g}\cdot R_{eq1}}{\cancel{i_b}\cdot R_{eq6}} =$$

$$= -62,63982$$

$R_g = 200\ \Omega$

$R_{eq1} = 6000\ \Omega$

$R_{eq2} = 4000\ \Omega$

$R_{eq3} = 303,2857143\ \Omega$

$R_{eq4} = 2400\ \Omega$

$R_{eq5} = 632100\ \Omega$

$R_{eq6} = -95785,71432\ \Omega$

ESERCIZIO B

Riduco la funzione booleana data in forma minima:

$$Y = (\overline{AE} + \bar{C}D)(\bar{B}D + E) + \bar{C}\bar{D}E + \bar{B}(AC + D)$$

$$Y = (\bar{A} + \bar{E} + \bar{C}D)(\bar{B}D + E) + \bar{C}\bar{D}E + \bar{B}AC + \bar{B}D$$

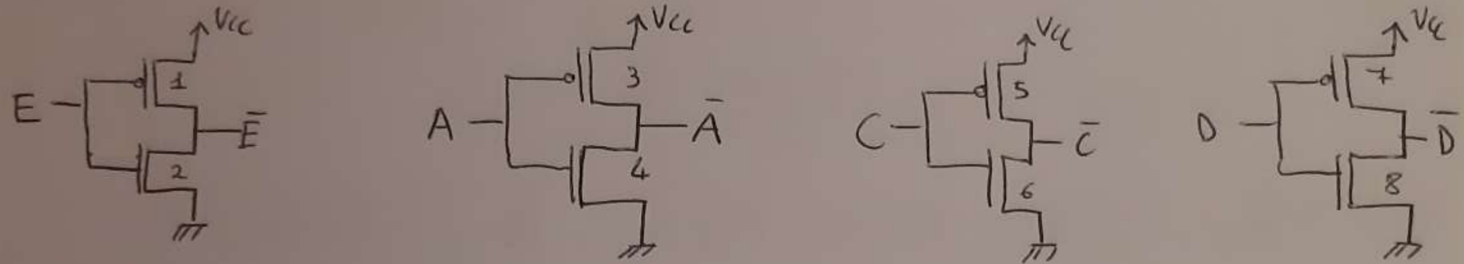
$$Y = \cancel{\bar{A}\bar{B}D} + \cancel{\bar{E}\bar{B}D} + \cancel{\bar{C}\bar{B}D} + \bar{A}E + \bar{C}DE + \bar{C}\bar{D}E + \bar{B}AC + \cancel{\bar{B}D}$$

$$Y = \bar{B}D + \bar{A}E + \bar{C}E + \bar{B}AC$$

$$Y = E(\bar{A} + \bar{C}) + \bar{B}(AC + D)$$

Realizzabile con $N = 2 \cdot 7 + 2 \cdot 4 = 22$ mosfet.

Generatori segnali negati

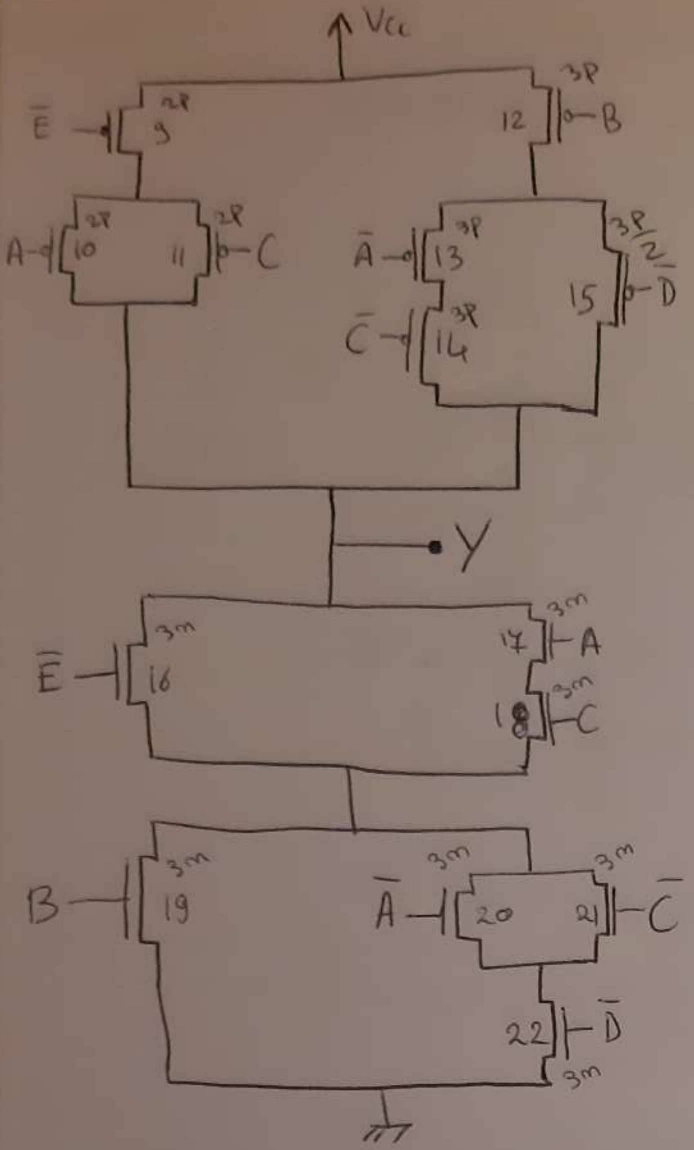


Inverter di Base

$$\left(\frac{W}{L}\right)_{1,3,5,7} = p = 5$$

$$\left(\frac{W}{L}\right)_{2,4,6,8} = n = 2$$

Disegno pull-up network e pull-down network (ottenuta per simmetria dalla PUN):



WORST CASE:

Conducono $Q_{17} - Q_{18} - Q_{19}$,
oppure $Q_{16} - Q_{20} - Q_{22}$,
oppure $Q_{16} - Q_{21} - Q_{22}$:

$$\left(\frac{W}{L}\right)_{\substack{16,17,18\\19,20,21\\22}} = z \qquad \frac{1}{z} + \frac{1}{z} + \frac{1}{z} = \frac{1}{m} \Rightarrow z = 3m = 6$$

DIMENSIONAMENTO

PUN — WORST CASE:

Conducono $Q_{12} - Q_{13} - Q_{14}$:

$$\left(\frac{W}{L}\right)_{12,13,14} = x \Rightarrow \frac{1}{x} + \frac{1}{x} + \frac{1}{x} = \frac{1}{p}$$

$$\Rightarrow x = 3p = 15$$

Conducono $Q_9 - Q_{10}$, $Q_9 - Q_{11}$

$$\left(\frac{W}{L}\right)_{9,10,11} = y \Rightarrow \frac{1}{y} + \frac{1}{y} = \frac{1}{p} \Rightarrow y = 2p$$

Conducono $Q_{12} - Q_{15}$, di cui Q_{12} è già dimensionato

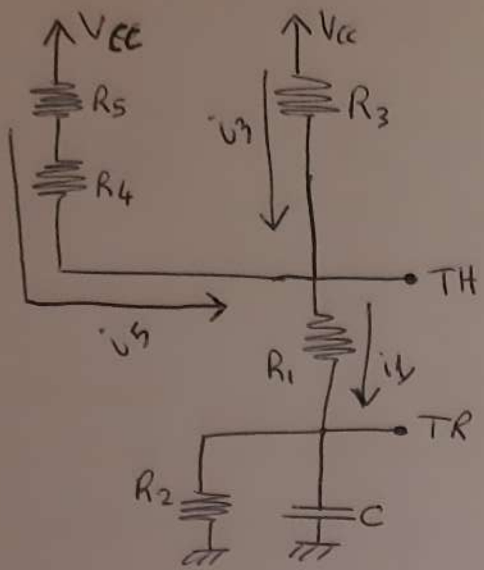
$$\left(\frac{W}{L}\right)_{15} = k \Rightarrow \frac{1}{k} + \frac{1}{15} = \frac{1}{p} \Rightarrow k = \frac{15}{2} = \frac{3p}{2}$$

PDN — WORST CASE:

I percorsi $Q_{17} - Q_{18} - Q_{20} - Q_{22}$ e $Q_{17} - Q_{18} - Q_{21} - Q_{22}$ non sono possibili per la presenza contemporanea nella serie di, rispettivamente, A e $\bar{A}$ ed C e $\bar{C}$.

ESERCIZIO C Q_1 NMOS

1) $\begin{cases} Q = 1 \\ D = 'HZ \end{cases} \Rightarrow \begin{matrix} V_{G1} = 0 \\ V_{S1} = 0 \end{matrix} \quad V_{GS1} = 0 < V_T \Rightarrow Q_1$ OFF

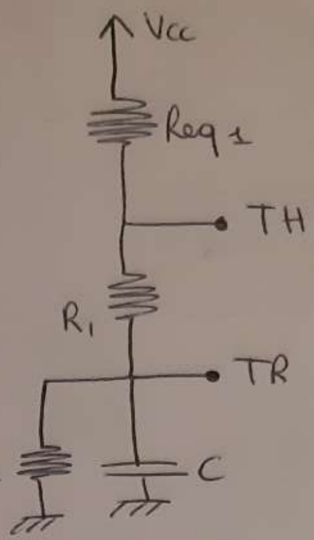


$i_1 = i_3 + i_5$

$i_3 = \dfrac{V_{CC} - V_{TH}}{R_3}$

$i_5 = \dfrac{V_{CC} - V_{TH}}{R_5 + R_4}$

$\Longrightarrow$



$R_{eq1} = (R_5 + R_4) // R_3 = 320\ \Omega$

$V_{i1} = \frac{1}{3} V_{CC} = 2V \qquad R_{eq2} = \dfrac{R_2}{R_{eq} + R_1 + R_2} = \dfrac{5}{6}\ \Omega$

$V_{asint1} = V_{CC} \cdot \dfrac{1}{R_{eq} + R_1 + R_2} \cdot R_2 = V_{CC} \cdot R_{eq2} = 5V$

$V_{TH} = \frac{2}{3} V_{CC} = 4V$

$V_{comm1} = V_{TH} - i_1 \cdot R_1 = 3{,}5V$

$\boxed{V_{i1} < V_{comm1} < V_{asint1}}$

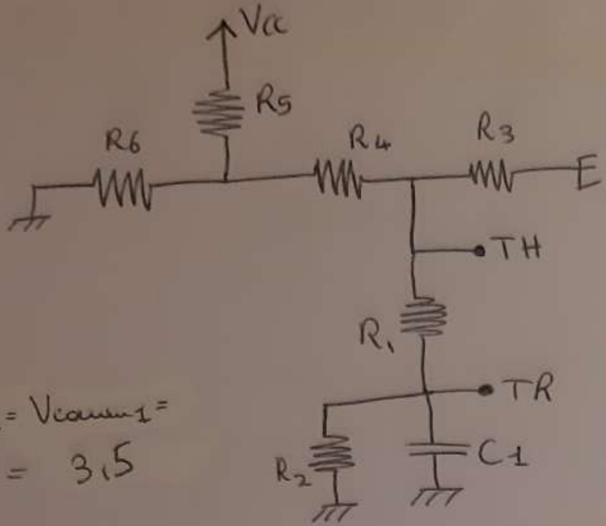
Ho effettivamente la commutazione.

$R_{vc1} = R_2 // (R_1 + R_{eq1}) = 333{,}3333\ \Omega$

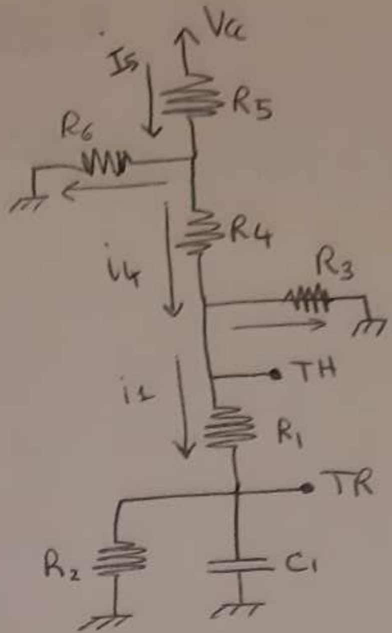
$\tau_1 = C \cdot R_{vc1} = \dfrac{1}{50000}\ s$

$T_1 = \tau_1 \cdot \ln\left(\dfrac{V_{i1} - V_{asint1}}{V_{comm1} - V_{asint1}}\right) = 1{,}386294 \cdot 10^{-5}\ s$

2) $\begin{cases} Q = 0 \\ D = 0 \end{cases} \Rightarrow \begin{matrix} V_{G1} = 6V \\ V_{S1} = 0V \end{matrix} \quad V_{GS1} = 6V > V_T \Rightarrow Q_1$ ON



$\rightleftharpoons$



$V_{i2} = V_{comm1} =$
$= 3{,}5$

$$i_5 = \frac{V_{cc}}{R_5 + R_6 // \left[R_4 + R_3 // \left(R_1 + R_2\right)\right]} = \frac{V_{cc}}{R_{eq1}} \qquad R_{eq1} = 1583{,}19325\ \Omega$$

$$i_4 = i_5 \cdot \frac{R_6}{R_6 + R_4 + R_3 // (R_1 + R_2)} = i_5 \cdot R_{eq2} \qquad R_{eq2} = \frac{62}{119}\ \Omega$$

$$i_1 = i_4 \cdot \frac{R_3}{R_3 + R_1 + R_2} = i_4 \cdot R_{eq3} = i_5 \cdot R_{eq2} \cdot R_{eq3} = \frac{V_{cc}}{R_{eq1}} \cdot R_{eq2} \cdot R_{eq3} \qquad R_{eq3} = \frac{5}{31}\ \Omega$$

$$V_{asint2} = i_1 \cdot R_2 = V_{cc} \cdot \frac{1}{R_{eq1}} \cdot R_{eq2} \cdot R_{eq3} \cdot R_2 = 0{,}6369427 V$$

$$V_{comm2} = \frac{1}{3} V_{cc} = 2V$$

$$\boxed{V_{i2} > V_{comm2} > V_{asint2}}$$

Ho effettivamente commutazione.

$$R_{vc2} = R_2 // \left[R_1 + R_3 // \left(R_4 + \left(R_6 // R_5\right)\right)\right] = 301{,}486199\ \Omega$$

$$\tau_2 = C \cdot R_{vc2} = 0{,}000018089\ s$$

$$T_2 = \tau_2 \cdot \ln\left(\frac{V_{i2} - V_{osint2}}{V_{comm2} - V_{osint2}}\right) = 1{,}342492 \cdot 10^{-5}\ s$$

$$2{,}728786 \cdot 10^{-5}\ s$$

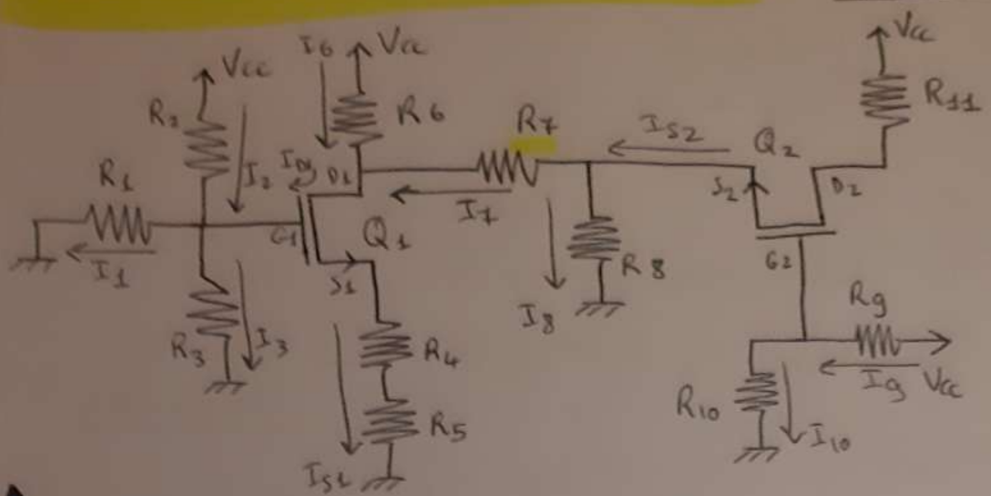
$$T = T_1 + T_2 =$$

$$36646{,}327\ Hz$$

$$f = \frac{1}{T} = .$$

Prova Scritta del 31 gennaio 2019

ESERCIZIO A) 1)



$V_{D2} = 13,1V$

$I_{D2} = \frac{V_{cc} - V_{D2}}{R_{11}} = 9,8 \cdot 10^{-4}$ A

$I_{G2} = 0 \Rightarrow I_{S2} = I_{D2}$

Circuito in continua con assegnate le correnti sui rami.

$$V_{G2} = V_{cc} \cdot \frac{R_{10}}{R_9 + R_{10}} = 12V$$

Q_2 in zona di saturazione: Ipotesi 1. $I_{D2} = K(V_{GS2} - V_T)^2$

$$V_{GS2} = V_T \pm \sqrt{\frac{I_{D2}}{K}}$$

$(V_{GS2} > V_T)$

Perchè Q_2 conduca $V_{GS2} = V_T + \sqrt{\frac{I_{D2}}{K}} = 2,4V$

$$I_8 = \frac{V_{S2}}{R_8} = 1 \cdot 10^{-4} A$$

$$V_{S2} = V_{G2} - V_{GS2} = 9,6V$$

$V_{DS2} = V_{D2} - V_{S2} = 3,5V \Rightarrow V_{DS2} > V_{GS2} - V_T = 1,4V$

[Ipotesi 1, saturazione di Q_2, verificata]

$$I_7 = I_{S2} - I_8 = 8,8 \cdot 10^{-4} A$$

$$V_{G1} = V_{CC} \cdot \frac{(R_1 // R_3)}{R_2 + (R_1 // R_3)} = 6V$$

Ipotesi 2: Q_1 in zona di saturazione.

$\Rightarrow I_{D1} = K(V_{GS1} - V_T)^2$

$$I_{D1} = K(V_{G1} - V_{S1} - V_T)^2$$

$I_{G1} = 0 \Rightarrow I_{S1} = I_{D1} \Rightarrow I_{S1} = K(V_{G1} - I_{S1}(R_4 + R_5) - V_T)^2$

$$I_{S1} = 0,5 \cdot 10^{-3}(6 - 1500\, I_{S1} - 1)^2$$

$$I_{S1} = 0,5 \cdot 10^{-3}(25 - 15000 \cdot I_{S1} + 1500^2 I_{S1}^2)$$

$I_{S1} = 0{,}0125 - 7{,}5\, I_{S1} + 1125\, I_{S1}^2$

$0{,}0125 - 8{,}5\, I_{S1} + 1125\, I_{S1}^2 = 0$

$I_{S1} = 5{,}5555 \cdot 10^{-3}\ A$

$I_{S1} = 2 \cdot 10^{-3}\ A$

$I_{S1} = 5{,}56 \cdot 10^{-3} A \Rightarrow V_{S1} = I_{S1}(R_4 + R_5) = 8{,}3334\,V$

$V_{GS1} = V_{G1} - V_{S1} = -2{,}3334\,V \leftarrow V_{GS1} < V_T$

Non va bene!

$I_{S1} = 2 \cdot 10^{-3} A \Rightarrow V_{S1} = 3V$

$V_{GS1} = 3V \leftarrow V_{GS1} > V_T$ Va bene!

$I_{D1} = I_{S1} = 2 \cdot 10^{-3} A$

$I_6 = I_{D1} - I_7 = 1.12 \cdot 10^{-3}\ A$

$V_{D1} = V_{CC} - I_6 R_6 = 9{,}04\,V$

$V_{DS1} = V_{D1} - V_{S1} = 6{,}04\ V \Rightarrow V_{DS1} > V_{GS1} - V_T = 2V$

Ipotesi di saturazione di Q_1 verificata.

$R_7 = \dfrac{V_{S2} - V_{D1}}{I_7} = 636.3636364\,\Omega$

$\boxed{\text{PUNTI DI RIPOSO}}$

Q_1:

$I_{D1} = 2 \cdot 10^{-3} A$

$V_{GS1} = 3V$

$V_{DS1} = 6{,}04\,V$

$g_{m_1} = 2k\,|V_{GS1} - V_T| =$
$= 2 \cdot 10^{-3}\ A/V$

Q_2:

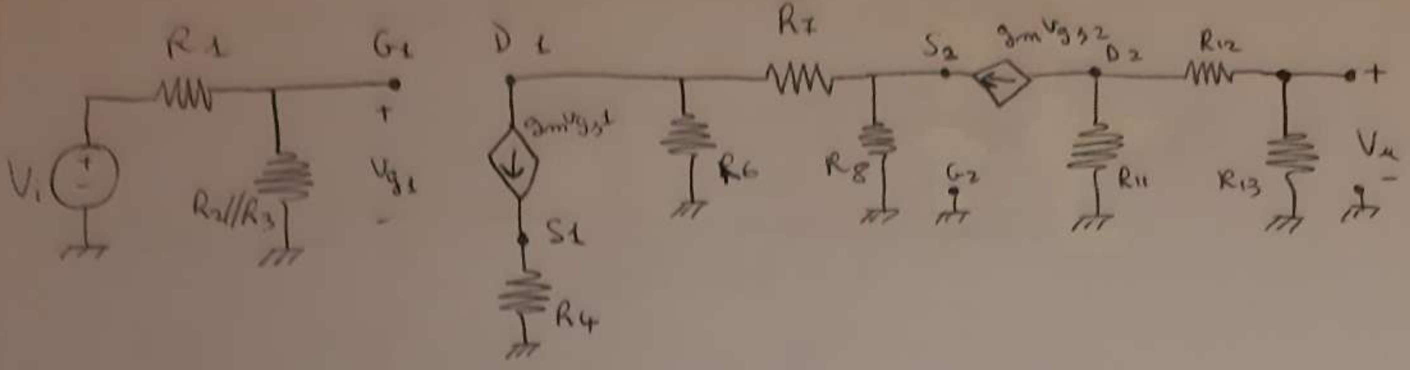
$I_{D2} = 9{,}8 \cdot 10^{-4} A$

$V_{GS2} = 2{,}4\ V$

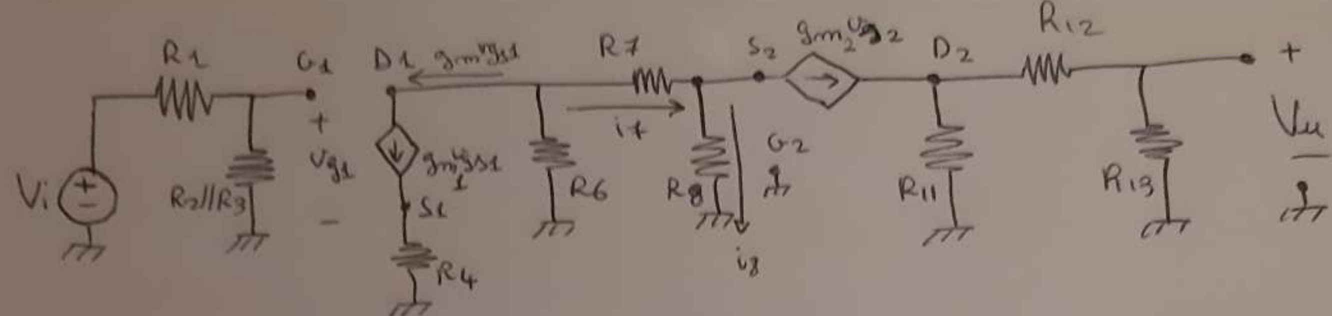
$V_{DS2} = 3{,}5\,V$

$g_{m_2} = 2k\,|V_{GS2} - V_T| =$
$= 1.4 \cdot 10^{-3}\ A/V$

ESERCIZIO A) 2) Circuito per le variazioni:



$v_{g_2} = 0 \Rightarrow g_m v_{gs2} = g_m(v_{g2} - v_{s2}) = -g_m v_{s2}$



$$V_u = g_{m_2} v_{s2} \cdot \frac{R_{11}}{R_{11}+R_{12}+R_{13}} \cdot R_{13} = g_{m_2} v_{s2} \cdot R_{eq1}$$

$R_{eq_1} = \frac{250000}{63} \, \Omega$

$v_{s2} = R_8 \cdot i_8$

$$i_7 = -g_{m_1} v_{gs1} \cdot \frac{R_6}{R_6 + R_7 + R_8 // (1/g_{m2})} = -g_{m1} v_{gs1} R_{eq_2}$$

$i_8 = i_7 - g_{m_2} v_{s2}$

$R_{eq_2} = 0{,}9263117\cancel{3} \, \Omega$

$v_{gs1} = v_{g1} - v_{s1} = v_{g1} - g_m v_{gs1} \cdot R_4$

$v_{g1} = v_{gs1} + g_{m_1} v_{gs1} R_4$

$$v_{gs1} = \frac{v_{g1}}{1 + g_{m_1} R_4}$$

$$v_{g1} = V_i \cdot \frac{R_2 // R_3}{R_1 + R_2 // R_3} = V_i \cdot R_{eq_3}$$

$R_{eq_3} = \frac{1}{3} \, \Omega$

$V_u = g_{m_2} v_{s2} \cdot R_{eq1} = g_{m_2} R_8 \cdot i_8 \cdot R_{eq1} =$

$$= g_{m2} \cdot R_8 \, \frac{-g_{m1} v_{gs1} \cdot R_{eq2}}{1 + g_{m2} R_8} \cdot R_{eq1} =$$

$$= g_{m2} R_8 \, \frac{-g_{m1} \cdot \left[\frac{V_i R_{eq3}}{1 + g_{m1} R_4} \right] \cdot R_{eq2}}{1 + g_{m2} R_8} \cdot R_{eq1} =$$

$$\frac{V_u}{V_i} = g_{m2} R_8 \cdot \frac{-g_{m1} \left[\frac{R_{eq3}}{1 + g_{m1} R_4} \right] \cdot R_{eq2}}{1 + g_{m2} R_8} \cdot R_{eq1} = -2,22778$$

ESERCIZIO B

Riduco la funzione booleana data in forma minima:

$$Y = \left(\overline{A+\bar D}\right)\left(\bar A\bar C + \bar B\right) + \bar A\left(\overline{C}\,\overline{D} + \bar E\right) + \left(\overline{\bar A + B}\right)(D+E)$$

$$Y = (\bar A\cdot D)(\bar A\bar C + \bar B) + \bar A\bar C\bar D + \bar A\bar E + (A\cdot\bar B)(D+E)$$

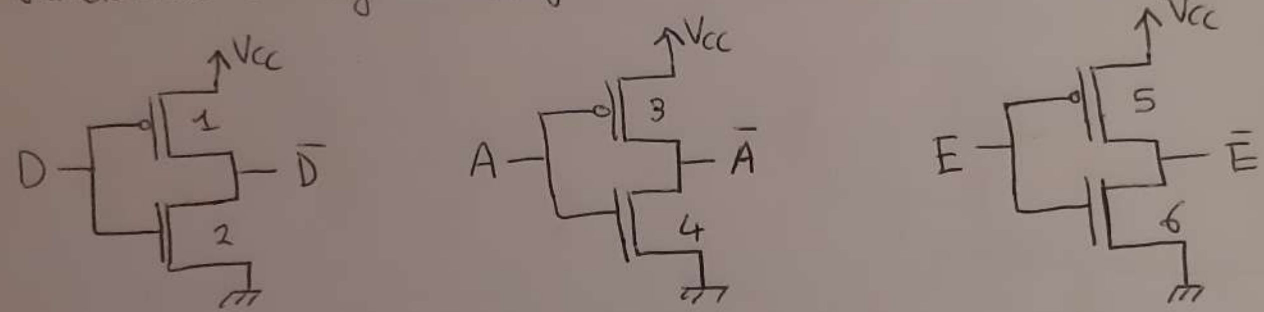
$$Y = \bar A\cancel{D}\bar C + \bar A\cancel{D\bar B} + \bar A\cancel{\bar C\bar D} + \bar A\bar E + \cancel{A\bar B}D + A\bar B E$$

$$Y = \bar A\bar C + \bar B D + \bar A\bar E + A\bar B E$$

$$Y = \bar A(\bar C + \bar E) + \bar B(D + AE)$$

Realizzabile con $N = 2\cdot 7 + 2\cdot 3 = 20$ mosfet.

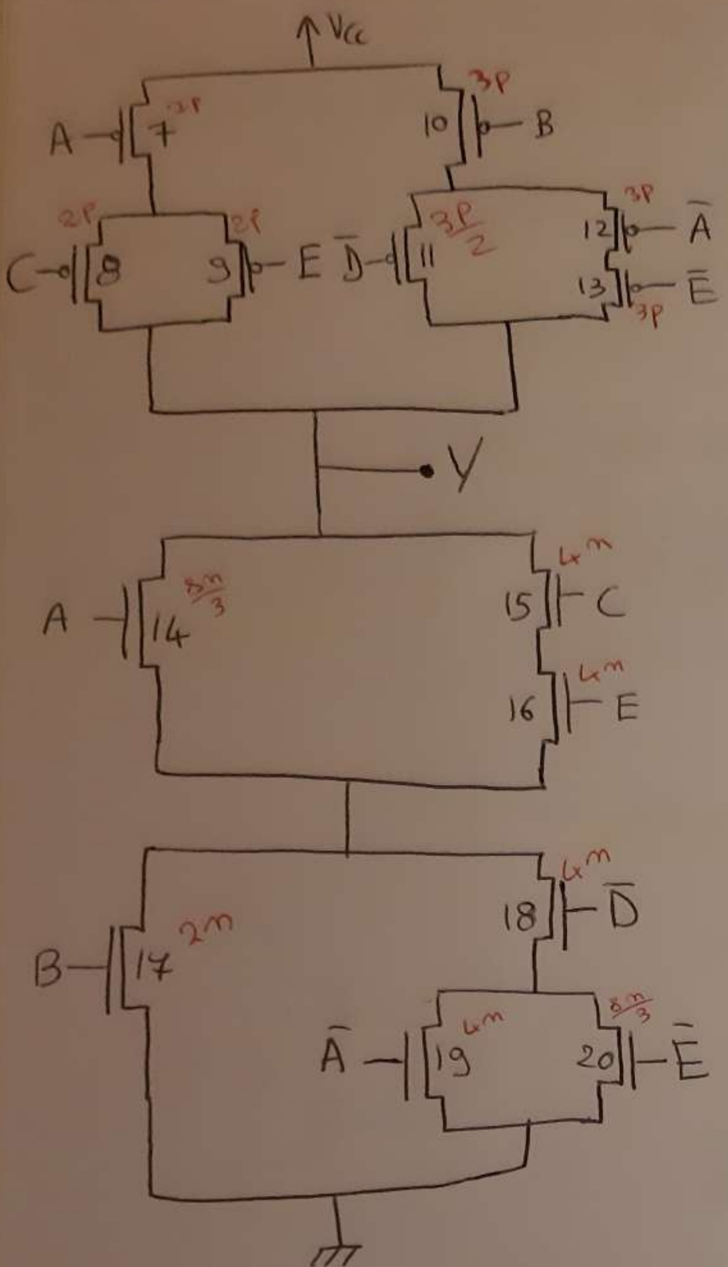
Generatori di segnali negati:



Inverter di base:

$$\left(\frac{W}{L}\right)_{1,3,5} = p = 5 \qquad \left(\frac{W}{L}\right)_{2,4,6} = n = 2$$

Disegno la pull-up network e la pull-down network (per simmetria rispetto alla PUN).



DIMENSIONAMENTO

PUN WORST CASE:

Conducono $Q_{10} - Q_{12} - Q_{13}$:

$$\left(\frac{W}{L}\right)_{10,12,13} = X$$

$$\frac{1}{X} + \frac{1}{X} + \frac{1}{X} = \frac{1}{p} \Rightarrow X = 3p = 15$$

Conducono $Q_7 - Q_8$ or $Q_7 - Q_9$:

$$\left(\frac{W}{L}\right)_{7,8,9} = Y$$

$$\frac{1}{Y} + \frac{1}{Y} = \frac{1}{p} \Rightarrow Y = 2p = 10$$

Conducono $Q_{10} - Q_{11}$ di cui Q_{10} già dimensionato:

$$\left(\frac{W}{L}\right)_{11} = Z$$

$$\frac{1}{Z} + \frac{1}{15} = \frac{1}{5} \Rightarrow Z = \frac{15}{2} = \frac{3p}{2}$$

PDN WORST CASE: Il percorso $Q_{15} - Q_{16} - Q_{18} - Q_{20}$ non è possibile per la contemporanea presenza di E ed $\bar{E}$.

Conducono $Q_{15} - Q_{16} - Q_{18} - Q_{19}$:

$$\left(\frac{W}{L}\right)_{15,16,18,19} = Z \Rightarrow \frac{1}{Z} + \frac{1}{Z} + \frac{1}{Z} + \frac{1}{Z} = \frac{1}{m} \Rightarrow Z = 4m = 8$$

Conducono $Q_{14} - Q_{18} - Q_{20}$ di cui $\left(\frac{W}{L}\right)_{18} = 4m$

$$\left(\frac{W}{L}\right)_{14,20} = Y \Rightarrow \frac{1}{Y} + \frac{1}{Y} + \frac{1}{4m} = \frac{1}{m}$$

$$\frac{2}{Y} = \frac{3}{4m} \Rightarrow Y = \frac{8m}{3}$$

Conducono $Q_{15} - Q_{16} - Q_{17}$ di cui $\left(\frac{W}{L}\right)_{15,16} = 4n$

$$\left(\frac{W}{L}\right)_{17} = K \Rightarrow \frac{1}{K} + \frac{1}{4n} + \frac{1}{4n} = \frac{1}{n}$$

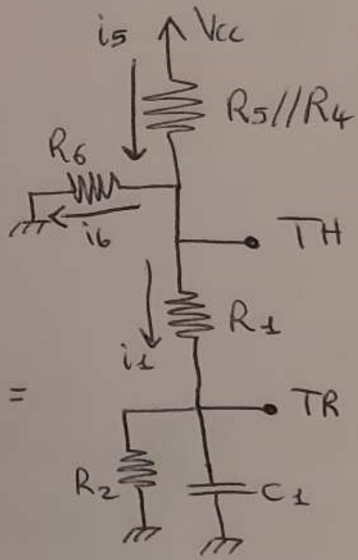
$$\frac{1}{K} = \frac{1}{2n} \Rightarrow K = 2n = 4$$

Il percorso $Q_{14} - Q_{18} - Q_{19}$ non è presente per la contemporanea presenza nella serie di A e $\bar{A}$.

$\boxed{\text{ESERCIZIO C}}$ $V_{i1} = \frac{1}{3}V_{cc} = 2V$

$$\begin{cases} Q = 1 \\ D = 'HZ \end{cases} \Rightarrow \begin{matrix} V_{G1} = \emptyset V, V_{S1} = \emptyset V, V_{GS1} = \emptyset V < V_T \Rightarrow Q_1 \text{ OFF} \\ V_{G2} = \emptyset V, V_{S2} = \emptyset V, V_{GS2} = \emptyset V < V_T \Rightarrow Q_2 \text{ OFF} \end{matrix}$$

$$i_5 = \frac{V_{cc}}{\underbrace{R_5 // R_4}_{400\Omega} + \underbrace{[R_6 // (R_1 + R_2)]}_{1500}} = \frac{V_{cc}}{R_{eq1}}$$



$$i_1 = i_5 \cdot \frac{R_6}{R_6 + R_1 + R_2} = i_5 \cdot R_{eq2}$$

$$V_{asint1} = i_1 \cdot R_2 = i_5 \cdot R_{eq2} \cdot R_2 = \frac{V_{cc}}{R_{eq1}} \cdot R_{eq2} \cdot R_2 =$$

$$= 4.5 V$$

$R_{eq1} = 1900\ \Omega$
$R_{eq2} = 3/4\ \Omega$
$R_2 = 1900\ \Omega$

$V_{TH} = \frac{2}{3} V_{cc} = 4V$

$$i_6 = \frac{V_{TH}}{R_6} = \frac{1}{1500} A$$

$$i_1 = i_5 - i_6 = \frac{13}{3000} A$$

$$i_5 = \frac{V_{cc} - V_{TH}}{R_5 // R_4} = \frac{1}{200} A$$

$$V_{comm1} = V_{TH} - i_1 \cdot R_1 = \frac{2}{3}V_{cc} - \frac{13}{3000} \cdot 100 = \frac{107}{30} V$$

$V_{i1} < V_{comm1} < V_{asint1} \Rightarrow$ Ho effettivamente commutazione.

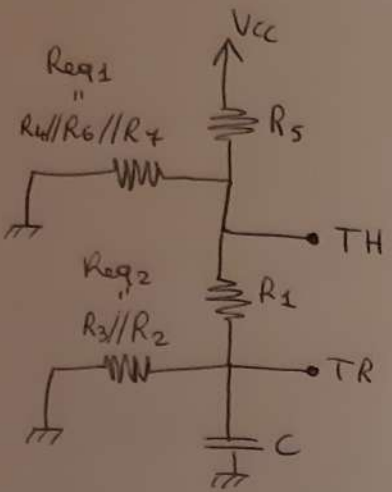
$V_a = \emptyset V$

$$R_{vc1} = R_2 // [\underbrace{R_1 + (\overbrace{R_6 // R_5 // R_4}^{375\,\Omega})}_{475}] = 380\,\Omega$$

$$\tau_1 = C \cdot R_{vc1} = 2,584 \cdot 10^{-4}\,s$$

$$T_1 = \tau_1 \cdot \ln\left(\frac{V_{i1} - V_{asint1}}{V_{comm1} - V_{asint1}}\right) = 2,545972 \cdot 10^{-4}\,s$$

$$\begin{cases} Q = 0 \\ D = 0 \end{cases} \Rightarrow \begin{array}{l} V_{G1} = 6V,\ V_{S1} = \emptyset V,\ V_{GS1} = 6V > V_T \Rightarrow Q_1 \text{ ON} \\ V_{G2} = 6V,\ V_{S2} = \emptyset V,\ V_{GS2} = 6V > V_T \Rightarrow Q_2 \text{ ON} \end{array}$$



$$V_{i2} = V_{comm1} = \frac{107}{30}\,V$$

$$V_{comm2} = \frac{1}{3} V_{cc} = 2V$$

$$V_{asint2} = \frac{V_{cc}}{\underbrace{R_5 + Req_1 // (R_1 + Req_2)}_{1005,378 \quad 205,37896\,\Omega}} \cdot \underbrace{\frac{Req_1}{Req_1 + R_1 + Req_2}}_{0,19559901\,\Omega} \cdot Req_2 = 1,1089504\,V$$

$Req_1 = 255,31914\,\Omega$

$Req_2 = 950\,\Omega$

$$\boxed{V_{i2} > V_{comm2} > V_{asint2}}$$

$V_{cc} = \emptyset V$

$$R_{vc2} = Req_2 // [R_1 + (Req_1 // R_5)] = 224,25421\,\Omega$$

$$\tau_2 = C \cdot R_{vc2} = 0,00015249\,s$$

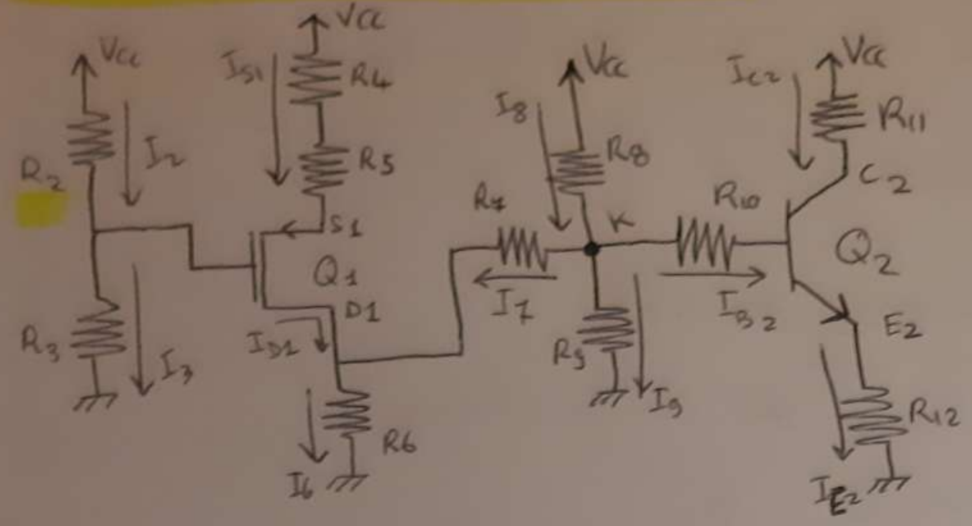
$$T_2 = \tau_2 \cdot \ln\left(\frac{V_{i2} - V_{asint2}}{V_{comm2} - V_{asint2}}\right) = 1,5471441 \cdot 10^{-4}\,s$$

$$T = T_1 + T_2 = 4,0931161 \cdot 10^{-4}\,s$$

$$f = \frac{1}{T} = 2443,126\ Hz$$

Prova Scritta del 10 gennaio 2019

ESERCIZIO A) 1)



Disegno il circuito in continua ed assegno le correnti sui rami:

$V_{C2} = 11V$

$$I_{C2} = \frac{V_{CC} - V_{C2}}{R_{11}} = 2 \cdot 10^{-3} A$$

Ipotesi 1: Q_2 in zona attiva diretta: $\begin{cases} I_{B2} \ll I_{C2} \\ I_{E2} = I_{C2} \end{cases}$

$V_{E2} = I_{E2} \cdot R_{12} = 6\,V$

$V_{CE2} = V_{C2} - V_{E2} = 5V$

Q_2 si trova nel punto di lavoro $I_{C2} = 2mA$, $V_{CE2} = 5\,V$, per cui il costruttore fornisce i seguenti valori tabulati

$\begin{cases} h_{FE} = 290 \\ h_{ie} = 4800 \\ h_{fe} = 300 \end{cases}$ $\quad I_{B2} = \frac{I_{C2}}{h_{FE}} = 6,896551 \cdot 10^{-6} A$

$V_{CE2} \geq V_{CESAT} = 0,2V \Rightarrow$ Ipotesi 1 verificata.

Per lo standard delle tecnologie odierne, possiamo assumere

$V_{BE2} = V_\gamma = 0,7V$

$V_{BE2} = V_{B2} - V_{E2} \Rightarrow V_{B2} = V_{BE2} + V_{E2} = 6,7\,V$

$V_K - V_{B2} = I_{B2} \cdot R_{10} \Rightarrow V_K = I_{B2} \cdot R_{10} + V_{B2} = 6,7199999\,V$

$$I_8 = \frac{V_{CC} - V_K}{R_8} = 1,128000 \cdot 10^{-3} A \qquad I_9 = \frac{V_K}{R_9} = 5,599999 \cdot 10^{-4} A$$

$I_7 = I_8 - I_{B2} - I_9 = 5,611034 \cdot 10^{-4}$

$V_k - V_{D1} = I_7 \cdot R_7 \Rightarrow V_{D1} = V_k - I_7 R_7 = 6,1588965\,V$

$I_6 = \frac{V_{D1}}{R_6} = 3,07944825 \cdot 10^{-3} A$

$I_{D1} = I_6 - I_7 = 2,51834485 \cdot 10^{-3} A$

<u>Ipotesi 2:</u> Q_1 in zona di saturazione:

$$I_{D1} = K(V_{GS1} - V_T)^2$$

$$V_{GS1} = V_T \pm \sqrt{\frac{I_{D1}}{K}}$$

Per la condizione di conduzione di Q_1 scelgo

$$V_{GS1} < V_T \Rightarrow V_{GS1} = V_T - \sqrt{\frac{I_{D1}}{K}} =$$

$$= -3,24425704\,V$$

$I_{G1} = 0 \Rightarrow I_{S1} = I_{D1}$

$V_a - V_{S1} = I_{S1}(R_4 + R_5) \Rightarrow V_{S1} = V_{cc} - I_{S1}(R_4 + R_5) =$

$$= 11,95597236\,V$$

$V_{DS1} = V_{D1} - V_{S1} = -5,79707586\,V$

Verifico la saturazione di Q_1 $V_{DS1} < V_{GS1} - V_T$

$-5,79\,V < (-3,244 + 1)\,V$

Saturazione verificata

$V_{GS1} = V_{G1} - V_{S1} \Rightarrow V_{G1} = V_{GS1} + V_{S1} = 8,7117153\,V$

$I_2 = I_3 = \frac{V_{G1}}{R_3} = 4,8398418 \cdot 10^{-4} A$

$V_{cc} - V_{G1} = R_2 I_2$

$$R_2 = \frac{V_{cc} - V_{G1}}{I_2} = 19191{,}29\ \Omega$$

$\boxed{\text{PUNTI DI RIPOSO}}$

$\underline{Q_1}$:

$I_{D1} = 2{,}5183 \cdot 10^{-3} A$

$V_{GS1} = -3{,}24425\ V$

$V_{DS1} = -5{,}79707\ V$

$g_m = 2K |V_{GS1} - V_T| =$

$= 2{,}24425 \cdot 10^{-3} A/V$

$\underline{Q_2}$:

$I_{C2} = 2 mA$

$V_{CE2} = 5\ V$

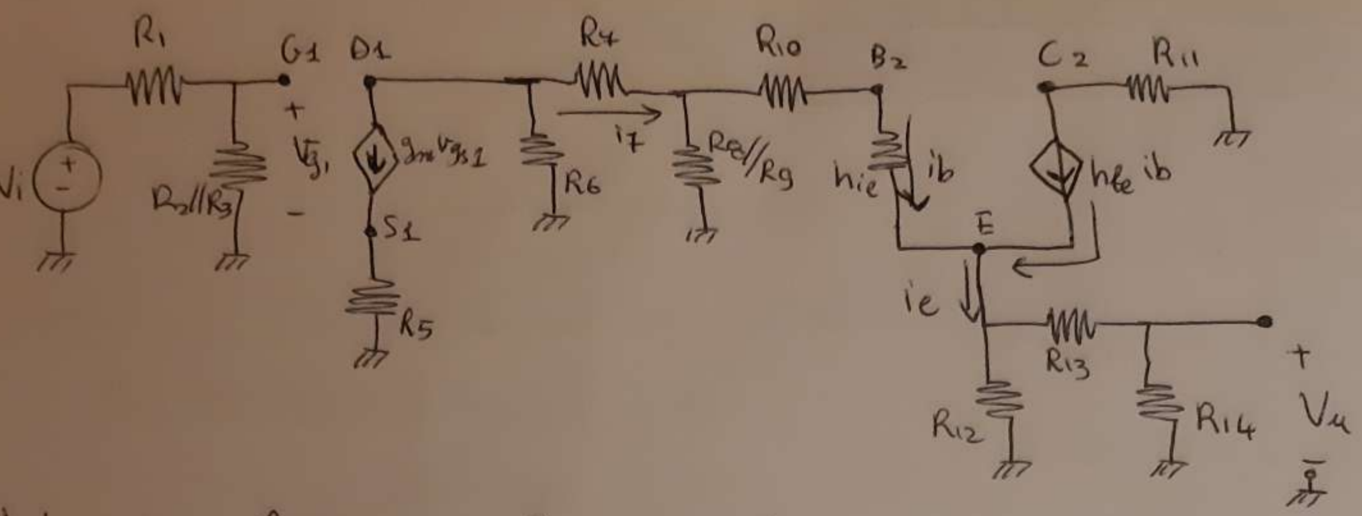
$I_{B2} = 6{,}896551\ \mu A$

$h_{fe} = 300$

$h_{ie} = 4800\ \Omega$

ESERCIZIO A) 2)

Disegno il circuito per le variazioni



$$V_u = i_e \cdot \frac{R_{12}}{R_{12}+R_{13}+R_{14}} \cdot R_{14} = i_e \cdot R_{eq_1}$$

$$i_e = h_{fe} \cdot i_b + i_b = i_b(h_{fe}+1)$$

$$R_v = h_{ie} + \left[R_{12} // (R_{13}+R_{14})\right](h_{fe}+1)$$

$$= 701006{,}1069$$

$$i_b = i_7 \cdot \frac{R_8//R_9}{R_8//R_9 + R_{10} + R_v} = i_7 \cdot R_{eq_2}$$

$$i_7 = -g_m v_{gs1} \cdot \frac{R_6}{R_6 + R_7 + \underbrace{(R_8//R_9)//(R_{10}+R_v)}_{5454{,}5454}} = R_{eq_3} \cdot -g_m v_{gs1}$$

$$v_{gs1} = v_{g1} - v_{s1} = v_{g1} - g_m v_{gs1} \cdot R_5$$

$$v_{gs1}(1+g_m R_5) = v_{g1} \Rightarrow v_{gs1} = \frac{v_{g1}}{1+g_m R_5}$$

$$v_{g1} = V_i \cdot \frac{R_2//R_3}{R_1 + R_2//R_3} = V_i \cdot R_{eq_4}$$

$$V_u = i_e \cdot R_{eq_1} = R_{eq_1} \cdot i_b(h_{fe}+1) = R_{eq_1} \cdot i_7 \cdot R_{eq_2} \cdot (h_{fe}+1) =$$

$$= R_{eq_1} \cdot R_{eq_3}(-g_m v_{gs1}) R_{eq_2} (h_{fe}+1) =$$

$$= R_{eq_1} \cdot R_{eq_3} \left(-g_m \cdot \left[\frac{v_{g1}}{1 + g_m R_5} \right] \right) R_{eq_2} (h_{fe} + 1) =$$

$$= R_{eq_1} \cdot R_{eq_3} \cdot \left(-g_m \left[\frac{V_i \cdot R_{eq_4}}{1 + g_m R_5} \right] \right) R_{eq_2} (h_{fe} + 1)$$

$$\frac{V_u}{V_i} = R_{eq_1} \cdot R_{eq_3} \left(-g_m \left[\frac{R_{eq_4}}{1 + g_m R_5} \right] \right) R_{eq_2} (h_{fe} + 1) =$$

$$= -2{,}78163$$

$R_{eq_1} = 2290{,}076336\ \Omega$

$R_{eq_3} = 0{,}23773853\ \Omega$

$R_{eq_4} = 0{,}9946456\ \Omega$

$R_{eq_2} = 7{,}6899825 \cdot 10^{-3}\ \Omega$

$h_{fe} + 1 = 301$

$g_m = 2{,}24425 \cdot 10^{-3}$

$R_5 = 50$

ESERCIZIO B

Riduco l'espressione booleana data in forma minima.

$$Y = \overline{(A+D)}(\bar B + \bar C\,\bar D + E) + (\overline{\bar A + D})(\bar C + E) + \bar A(\bar B D + C\bar E)$$

$$Y = (\bar A\,\bar D)(\bar B + \bar C\,\bar D + E) + (A\bar D)(\bar C + E) + \bar A(\bar B D + C\bar E)$$

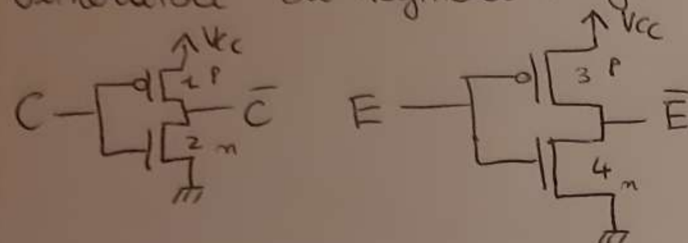
$$Y = \bar A\cancel{\bar D}\bar B + \cancel{\bar A\bar C\bar D} + \cancel{\bar A}\bar D E + \cancel{A}\bar D\bar C + \cancel{A\bar D E} + \bar A\bar B\cancel{D} + \bar A C\bar E$$

$$Y = \bar A\bar B + \bar D E + \bar D\bar C + \bar A C\bar E$$

$$Y = \bar A(\bar B + C\bar E) + \bar D(E + \bar C)$$

Realizzabile con $N = 2\cdot 7 + 2\cdot 2 = 18$ mosfet.

Generatori di segnali negati:

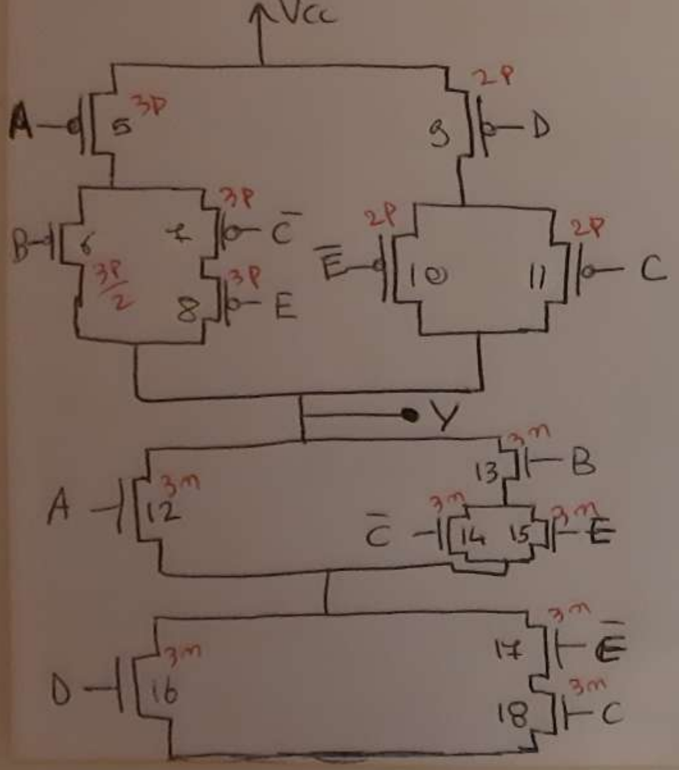


INVERTER DI BASE:

$$\left(\frac{W}{L}\right)_{1,3} = p = 5$$

$$\left(\frac{W}{L}\right)_{2,4} = n = 2$$

Disegno la pull up network e per simmetria ottengo la pull down network



DIMENSIONAMENTO

PUN: WORST CASE:

Conducono $Q_5 - Q_7 - Q_8$:

$$\left(\frac{W}{L}\right)_{5,7,8} = x \Rightarrow \frac{1}{x}+\frac{1}{x}+\frac{1}{x} = \frac{1}{p} \Rightarrow x = 3p$$

Conducono $Q_9 - Q_{10}$ oppure $Q_9 - Q_{11}$:

$$\left(\frac{W}{L}\right)_{9,10,11} = k \Rightarrow \frac{1}{k}+\frac{1}{k} = \frac{1}{p} \Rightarrow k = 2p$$

Conducono $Q_5 - Q_6$ con $\left(\frac{W}{L}\right)_5 = 3p$

$$\left(\frac{W}{L}\right)_6 = z \Rightarrow \frac{1}{z}+\frac{1}{3p} = \frac{1}{p} \Rightarrow z = \frac{3p}{2}$$

PDN: WORST CASE:

$Q_{13} - Q_{14} - Q_{17} - Q_{18}$ non possibile

$Q_{13} - Q_{15} - Q_{17} - Q_{18}$ non possibile

Conducono $Q_{13} - Q_{14} - Q_{16}$ oppure

$Q_{13} - Q_{15} - Q_{16}$ oppure

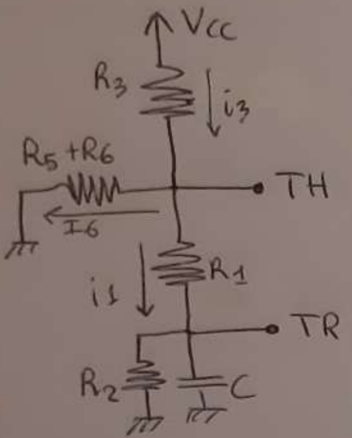
$Q_{12} - Q_{17} - Q_{18}$:

$$\left(\frac{W}{L}\right)_{\substack{12,13,14\\15,16,17\\18}} = f \Rightarrow \frac{1}{f} + \frac{1}{f} + \frac{1}{f} = \frac{1}{n} \Rightarrow f = 3n = 6$$

ESERCIZIO C

Q_1	N-MOS
Q_2	P-MOS

$$\begin{cases} Q = 1 \\ D = \text{'HZ} \end{cases} \Rightarrow \begin{array}{l} V_{G2} = 0V,\ V_{S2} = 6V,\ V_{GS2} = -6V < V_{T2} \Rightarrow Q_2 \text{ ON} \\ V_{G1} = 0V,\ V_{S1} = 0V,\ V_{GS1} = 0V < V_{T1} \Rightarrow Q_1 \text{ OFF} \end{array}$$



$$V_{i1} = \frac{1}{3}V_{cc} = 2V$$

$$i_3 = \frac{V_{cc}}{R_3 + (R_5 + R_6)//(R_1 + R_2)} = \frac{V_{cc}}{R_{eq1}}$$

$$R_{eq1} = 1000\ \Omega$$

$$i_1 = i_3 \cdot \frac{R_5 + R_6}{R_5 + R_6 + R_1 + R_2} = i_3 \cdot R_{eq2}$$

$$R_{eq2} = \frac{4}{5}\ \Omega$$

$$V_{osint1} = i_1 \cdot R_2 = i_3 \cdot R_{eq2} R_2 = \frac{V_{cc}}{R_{eq1}} \cdot R_{eq2} \cdot R_2 = 3{,}84V$$

$$V_{commu1} = V_{TH} - i_1 R_1 = V_{TH} - (I_3 - I_6) R_1 =$$

$V_{TH} = \frac{2}{3}V_{cc} = 4V$

$$= V_{TH} - \left(\frac{V_{cc} - V_{TH}}{R_3} - \frac{V_{TH}}{R_5 + R_6}\right) \cdot R_1 =$$

$$= \frac{2}{3}V_{cc} - \left(\frac{V_{cc} - \frac{2}{3}V_{cc}}{R_3} - \frac{\frac{2}{3}V_{cc}}{R_5 + R_6}\right) R_1 =$$

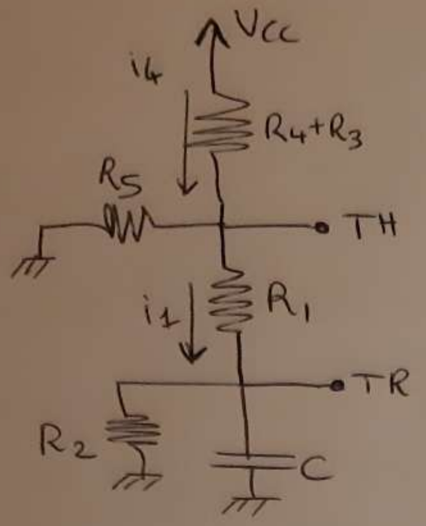
$$= 2{,}2V$$

Ho effettivamente la

$$\boxed{V_{i1} < V_{commu1} < V_{osint1}}$$

commutazione.

$\begin{cases} Q=0 \\ D=0 \end{cases} \Rightarrow \begin{array}{l} V_{G2}=6V,\ V_{S2}=6V,\ V_{GS2}=\emptyset V > V_{T2} \Rightarrow Q_2 \text{ OFF} \\ V_{G1}=6V,\ V_{S1}=0V,\ V_{GS2}=6V > V_{T1} \Rightarrow Q_1 \text{ ON} \end{array}$



$V_{i2} = V_{comm\,1} = 2{,}2V$

$V_{comm\,2} = V_{i1} = \frac{1}{3}V_{cc} = 2V$

$i_4 = \dfrac{V_{cc}}{R_4+R_3+R_5/\!/(R_1+R_2)} = \dfrac{V_{cc}}{R_{eq1}}$

$R_{eq1} = 4375\ \Omega$

$i_1 = i_4 \cdot \dfrac{R_5}{R_5+R_1+R_2} = i_4 \cdot R_{eq2}$

$R_{eq2} = \dfrac{3}{8}\ \Omega$ $\quad V_{asint2} = i_1 \cdot R_2 = i_4 \cdot R_{eq2} R_2 = \dfrac{V_{cc}}{R_{eq1}} \cdot R_{eq2} \cdot R_2 =$

$= 0{,}4114285 7$

$\boxed{V_{i2} > V_{comm2} > V_{asint2}}$ Ho effettivamente commutazione

$R_{vc1} = R_2/\!/[R_1 + (R_5+R_6)/\!/(R_3)] = 262{,}39999 8$ $\quad \tau_1 = C R_{vc1} = 2{,}6239 \cdot 10^{-4}\ s$

$V_{cc}=\emptyset$ $\quad 200 + 190{,}47619 = 390{,}47619$

$T_1 = \tau_1 \cdot \ln\left(\dfrac{V_{i1} - V_{asint1}}{V_{comm1} - V_{asint1}}\right) = 3{,}0194192 \cdot 10^{-5}\ s$

$R_{vc2} = R_2/\!/\left[R_1 + \left(R_5/\!/(R_4+R_3)\right)\right] = 379{,}428\ \Omega$

$721{,}7391304$

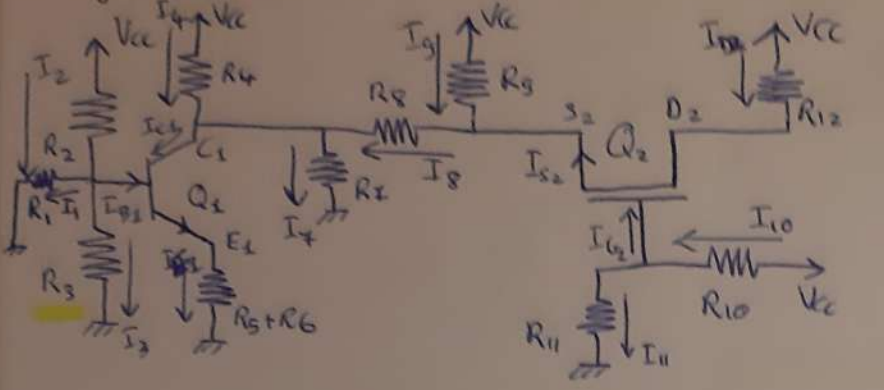
$\tau_2 = C \cdot R_{vc2} = 3{,}794285 \cdot 10^{-4}\ s$

$T_2 = \tau_2 \cdot \ln\left(\dfrac{V_{i2} - V_{asint2}}{V_{comm2} - V_{asint2}}\right) = 0{,}000044 9934\ s$

$T = T_1 + T_2 = 0{,}0000751876\ s \Longrightarrow f = \frac{1}{T} = 13300{,}065\ Hz$

Prova Scritta del 13 Settembre 2018 — ESERCIZIO A) 1)

Disegno il circuito in continua e assegno le correnti sui rami:



$V_{D_2} = 12V$

$I_{G_2} = 0 \Rightarrow I_{10} = I_{11}$

$\Rightarrow I_{S_2} = I_{D2}$

$I_{D2} = \frac{V_{cc} - V_{D2}}{R_{12}} = 2 \cdot 10^{-3} A$

$V_{G2} = V_{cc} \cdot \frac{R_{11}}{R_{11} + R_{10}} = 12V$

Ipotesi 1: Q_2 in zona di saturazione.

$\Rightarrow I_{D2} = K(V_{GS2} - V_T)^2 \Rightarrow V_{GS2} = V_T \pm \sqrt{\frac{I_{D2}}{K}}$

Per la condizione di conduzione di Q_2 $(V_{GS2} > V_T)$:

$$V_{GS2} = V_T + \sqrt{\frac{I_{D2}}{K}} = 3V$$

$V_{GS2} = V_{G2} - V_{S2} \Rightarrow V_{S2} = V_{G2} - V_{GS2} = 9V$

$V_{DS2} = V_{D2} - V_{S2} = 3V$

Verifico la saturazione di Q_2: $V_{DS2} \geq V_{GS2} - V_T$

$\boxed{3V \geq 2V}$ Ipotesi 1 verificata.

$I_9 = \frac{V_{cc} - V_{S2}}{R_9} = 2{,}5 \cdot 10^{-4} A$ $\quad$ $I_8 = I_9 + I_{S2} = 2{,}25 \cdot 10^{-3} A$

$V_{C1} = V_{S2} - I_8 R_8 = 8{,}55V$ $\quad$ $I_7 = \frac{V_{C1}}{R_7} = 7{,}5 \cdot 10^{-4} A$

$I_4 = \frac{V_{cc} - V_{C1}}{R_4} = 5 \cdot 10^{-4} A$ $\quad$ $I_{C1} = I_4 + I_8 - I_7 = 2 \cdot 10^{-3} A$

Ipotesi 2: Q_1 in zona attiva diretta: $\Rightarrow I_{B1} \ll I_{C1} \Rightarrow I_{E1} = I_{C1}$

$V_{E1} = I_{E1} \cdot (R_5 + R_6) = 3{,}55V$ $\quad$ $V_{CE1} = \cancel{V}_{C1} - V_{E1} = 5V$

Q_1 si trova nel punto di lavoro $I_{C1} = 2mA$, $V_{CE1} = 5V$, per cui il costruttore fornisce i seguenti valori tabulati:

$$\begin{cases} h_{FE} = 290 \\ h_{ie} = 4800\ \Omega \\ h_{fe} = 300 \end{cases} \qquad I_{B_1} = \frac{I_{C1}}{h_{FE}} = 6{,}8965517 \cdot 10^{-6} A$$

$V_{BE1} = V_\gamma = 0{,}7\ V$ ← per gli standard delle tecnologie odierne.

$V_{B1} = V_{BE1} + V_{E1} = 4{,}25\ V$

$I_2 = \frac{V_{CC} - V_{B1}}{R_2} = 10^{-3}\ A$

$I_1 = \frac{V_{B1}}{R_1} = 4{,}25 \cdot 10^{-4} A$

$I_3 = I_2 - I_{B1} - I_1 = 5{,}681 \cdot 10^{-4}\ A$

$R_3 = \frac{V_{B1}}{I_3} = 7481{,}031\ \Omega$

PUNTI DI RIPOSO

Q1:

$I_{C1} = 2\ mA$

$V_{CE1} = 5\ V$

$I_{B1} = 6{,}8965517 \cdot 10^{-6} A$

$h_{fe} = 300$

$h_{ie} = 4800\ \Omega$

Q2:

$I_{D2} = 2 \cdot 10^{-3} A$

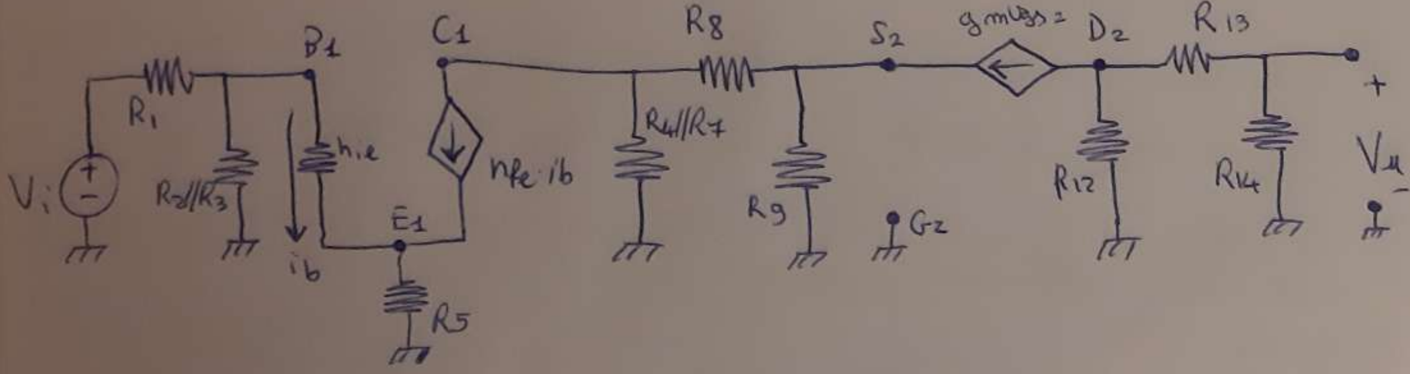
$V_{GS2} = 3\ V$

$V_{DS2} = 3\ V$

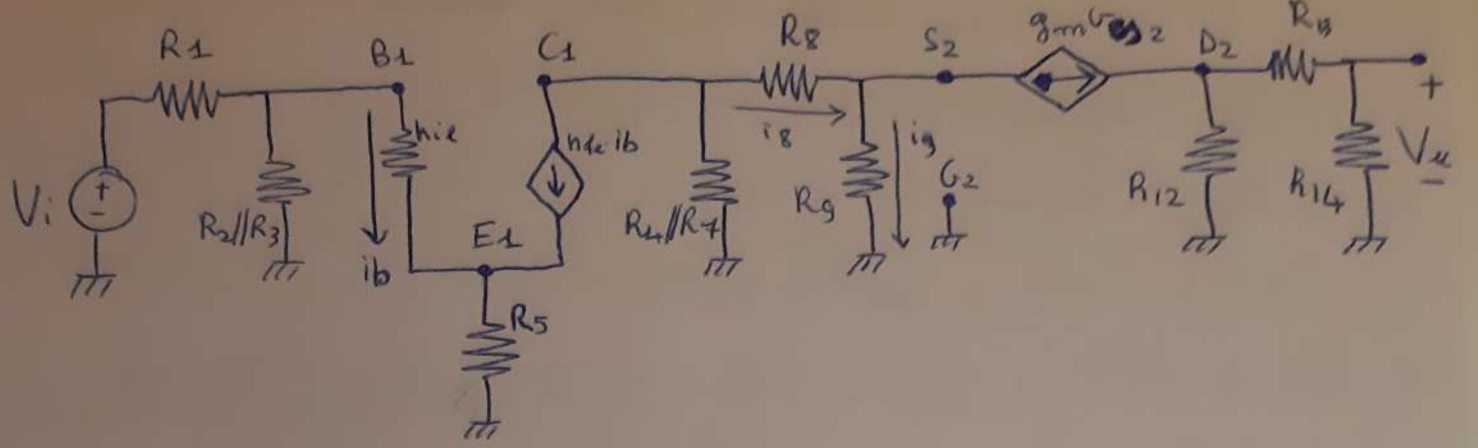
$g_m = 2K|V_{GS2} - V_T| = 2 \cdot 10^{-3} A/V$

ESERCIZIO A) 2)

Disegno il circuito per le variazioni e assegno le correnti sui rami:



$v_{g_2} = 0 \Rightarrow v_{gs_2} = v_{g_2} - v_{s_2} = -v_{s_2} \Rightarrow g_m v_{gs_2} = -g_m v_{s_2}$



$$V_u = g_m v_{s_2} \cdot \frac{R_{12}}{R_{12} + R_{13} + R_{14}} \cdot R_{14} = g_m v_{s_2} \cdot R_{eq_1}$$

$R_{eq_1} = 2500\ \Omega$ $\qquad v_{s_2} = i_g \cdot R_9$

$R_4 // R_7 = 7110{,}891089\ \Omega$

$R_9 // \frac{1}{g_m} = 493{,}150684\ \Omega$

$i_g = i_8 - g_m v_{s_2}$

$$i_8 = -h_{fe} \cdot i_b \cdot \frac{R_4//R_7}{R_4//R_7 + R_8 + R_9//\frac{1}{g_m}} = -h_{fe} \cdot i_b \cdot R_{eq_2}$$

$R_{eq_2} = 0{,}911805518$ $\qquad R_v = h_{ie} + R_5 (h_{fe} + 1) = 27375\ \Omega$

$$i_b = \frac{V_{B1}}{R_v} \qquad V_{B1} = V_i \cdot \frac{R_2//R_3//R_v}{R_1 + R_2//R_3//R_v} = V_i \cdot R_{eq_3}$$

$R_2 // R_3 // R_v = 4116{,}4304\ \Omega$ $\qquad i_b = \frac{V_i R_{eq_3}}{R_v}$

$R_{eq_3} = 0{,}2916056172\ \Omega$

$$\frac{V_u}{V_i} = g_m \cdot \frac{-h_{fe} \cdot \frac{R_{eq_3}}{R_v} \cdot R_{eq_2} \cdot R_9}{1 + g_m \cdot R_9} \cdot R_{eq_1} = -7{,}17986$$

ESERCIZIO B

Riduco la funzione booleana data in forma minima:

$$Y = (\overline{A+\bar B})(\bar C + \bar D E) + B(\bar A C + A\bar D \bar E) + \bar C \bar E + \bar C D$$

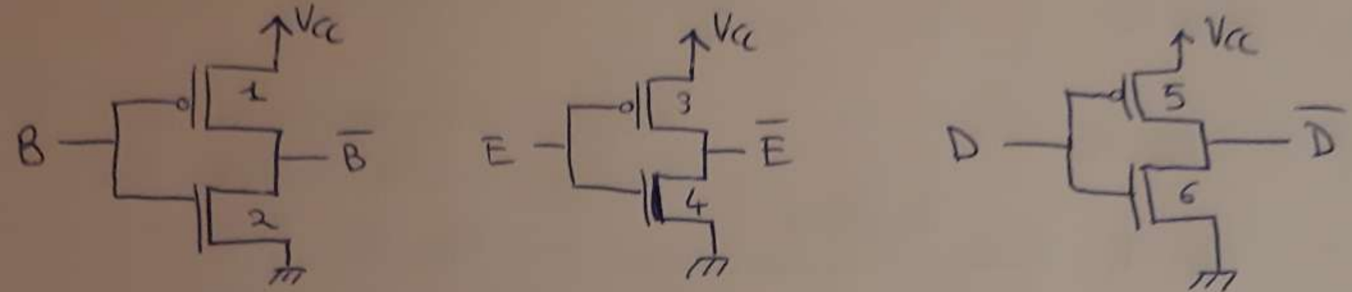
$$Y = (\bar A \cdot B)(\bar C + \bar D E) + B\bar A C + BA\bar D \bar E + \bar C \bar E + \bar C D$$

$$Y = \bar A B \bar C + \bar A B \bar D E + \cancel{B\bar A C} + B\cancel{A}\bar D E + \bar C \bar E + \bar C D$$

$$Y = \bar A B + B\bar D E + \bar C \bar E + \bar C D = B(\bar A + \bar D E) + \bar C(\bar E + D)$$

Realizzabile con $N = 2 \cdot 7 + 2 \cdot 3 = 20$ mosfet.

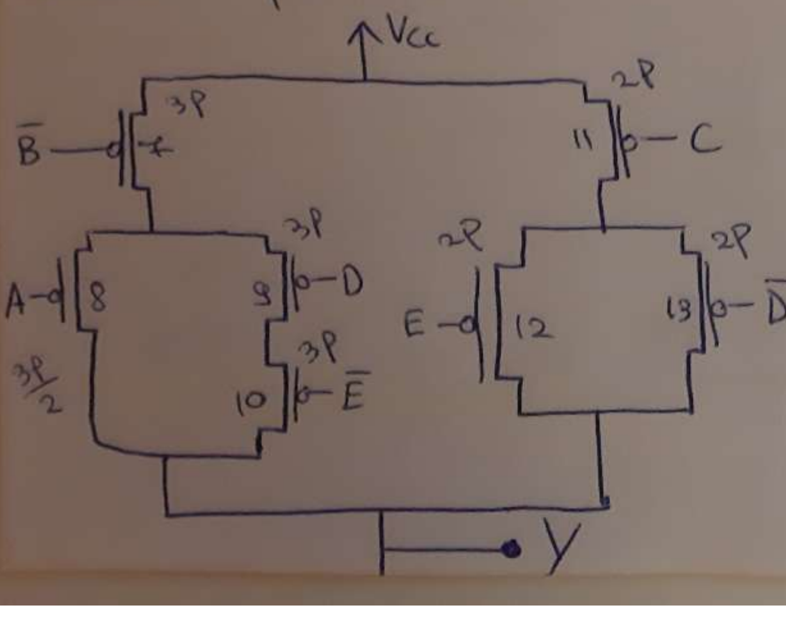
Generatori di segnali negati:

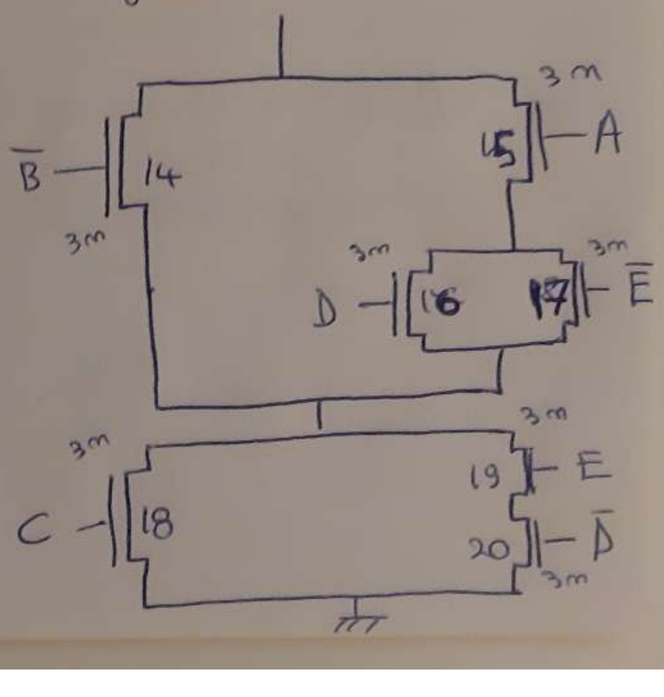


Inverter di base:

$$\left(\frac{W}{L}\right)_{1,3,5} = p = 5 \qquad \left(\frac{W}{L}\right)_{2,4,6} = n = 2$$

Disegno la pull up network e ottengo la pull down network per simmetria:





DIMENSIONAMENTO

Pull-up Network: WORST CASE:

Conducono $Q_7 - Q_9 - Q_{10}$:

$$\left(\frac{W}{L}\right)_{7,9,10} = x \Rightarrow \frac{1}{x} + \frac{1}{x} + \frac{1}{x} = \frac{1}{p} \Rightarrow x = 3p = 15$$

Conducono $Q_{11} - Q_{12}$ oppure $Q_{11} - Q_{13}$:

$$\left(\frac{W}{L}\right)_{11,12,13} = k \Rightarrow \frac{1}{k} + \frac{1}{k} = \frac{1}{p} \Rightarrow k = 2p = 10$$

Conducono $Q_7 - Q_8$ con $\left(\frac{W}{L}\right)_7 = 3p$

$$\left(\frac{W}{L}\right)_8 = f \Rightarrow \frac{1}{f} + \frac{1}{3p} = \frac{1}{p} \Rightarrow f = \frac{3p}{2} = 7,5$$

Pull down Network: WORST CASE:

I percorsi $Q_{15} - Q_{16} - Q_{19} - Q_{20}$ e $Q_{15} - Q_{17} - Q_{19} - Q_{20}$ non sono possibili per la presenza, rispettivamente, di D e $\bar{D}$ e di E ed $\bar{E}$ nella serie.

Conducono $Q_{15} - Q_{16} - Q_{18}$,

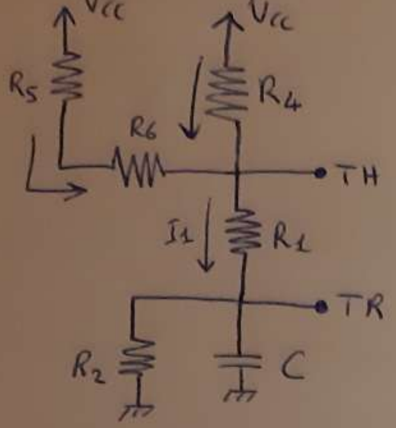
oppure $Q_{15} - Q_{17} - Q_{18}$,

oppure $Q_{14} - Q_{19} - Q_{20}$:

$$\left(\frac{W}{L}\right)_{14,15,16,17,18,19,20} = z \Rightarrow \frac{1}{z} + \frac{1}{z} + \frac{1}{z} = \frac{1}{n} \Rightarrow z = 3n = 6$$

ESERCIZIO C

$\begin{cases} Q=1 \\ D='HZ' \end{cases} \Rightarrow V_{G1}=0,\ V_{S1}=V_{cc},\ V_{GS1}=-6V < V_T \Rightarrow Q_1$ ON



$V_{i1} = \frac{1}{3} V_{cc} = 2V$

$$V_{asint1} = V_{TH} \cdot \frac{R_2}{R_1+R_2} = V_{TH} \cdot R_{eq1}$$

$$V_{TH} = V_{cc} \cdot \frac{R_1+R_2}{R_4//(R_5+R_6)+R_1+R_2} = V_{cc} \cdot R_{eq2}$$

$V_{TH} = \frac{2}{3} V_{cc} = 4V$

$V_{asint1} = V_{cc} \cdot R_{eq2} \cdot R_{eq1} = 4V$

$R_{eq2} = \frac{11}{15}\ \Omega$

$R_{eq1} = \frac{10}{11}\ \Omega$

$V_{commut1} = V_{TH} - I_1 \cdot R_1 = 3,5V$

$I_1 = \frac{V_{cc}-V_{TH}}{R_4} + \frac{V_{cc}-V_{TH}}{R_5+R_6} = 1,25 \cdot 10^{-3}$ A

$V_{i1} < V_{commut1} < V_{asint1} \Rightarrow$ Ho effettivamente la commutazione

$R_{vc1} = R_2 // [R_1 + (R_4//(R_5+R_6))] = 1333,333333\ \Omega$

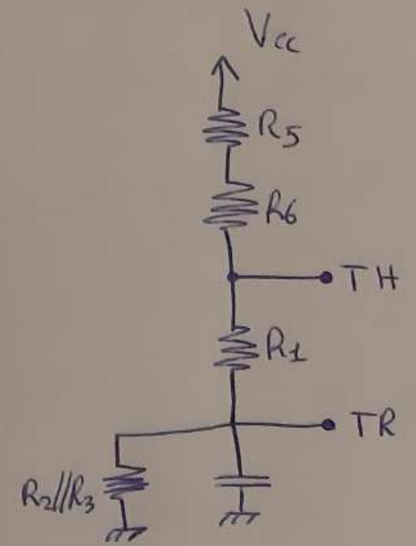
$\tau_1 = C \cdot R_{vc1} = 6,2666667 \cdot 10^{-4}$ s

$T_1 = \tau_1 \cdot \ln\left(\frac{V_{i1}-V_{asint1}}{V_{commut1}-V_{asint1}}\right) = 8,687444 \cdot 10^{-4}$ s

$\begin{cases} Q=0 \\ D=0 \end{cases} \Rightarrow Q_1$ OFF

$R_{eq3} = \frac{2}{3}\ \Omega$

$R_{eq} = \frac{3}{23}\ \Omega$



$V_{i2} = V_{commut1} = 3,5V$

$V_{commut2} = V_{i1} = 2V$

$$V_{asint2} = V_{TH} \cdot \frac{R_2//R_3}{R_1+R_2//R_3} = V_{TH}\ R_{eq3}$$

$$V_{TH} = V_{cc} \cdot \frac{R_1+R_2//R_3}{R_5+R_6+R_1+R_2//R_3} = V_{cc} \cdot R_{eq4}$$

$V_{asint2} = V_{cc} \cdot R_{eq4} \cdot R_{eq3} = 0,5217391\ V$

$V_{i2} > V_{commut2} > V_{asint2} \Rightarrow$ Ho effettivamente commutazione

$R_{UC2} = R_2 // R_3 // (R_1 + R_5 + R_6) = 780,4347826\ \Omega$

$\tau_2 = C \cdot R_{UC2} = 3,4330434 \cdot 10^{-4}\ s$

$T_2 = \tau_2 \cdot \ln\left(\frac{V_{i2} - V_{osimt2}}{V_{a\ldots 2} - V_{osimt2}}\right) = 2,40475498 \cdot 10^{-4}\ s$

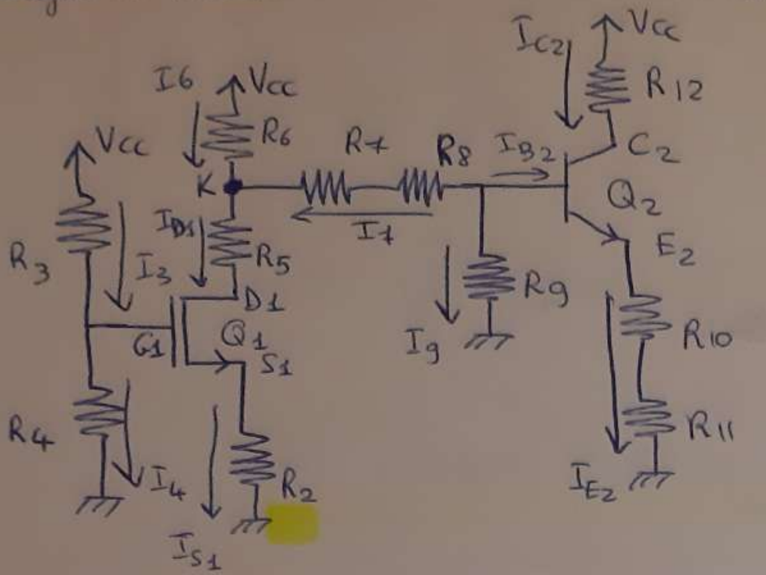
$T = T_1 + T_2 = 1,109219899 \cdot 10^{-3}\ s$

$f = \frac{1}{T} = 901,534494\ Hz$

Prova Scritta del 19 Luglio 2018

ESERCIZIO A) 1)

Disegno il circuito in continua e assegno le correnti sui rami:



$V_{C2} = 10V$

$I_{C2} = \frac{V_{CC} - V_{C2}}{R_{12}} = 2 \cdot 10^{-3} A$

Ipotesi 1: Q_2 in zona attiva diretta.

$\Rightarrow I_{B_2} << I_{C2} \Rightarrow I_{E_2} = I_{C2}$

$V_{E2} = I_{E2} \cdot (R_{10} + R_{11}) = 5V$

$V_{CE2} = V_{C2} - V_{E2} = 5V \Rightarrow V_{CE2} \geq V_{CESAT} = 0{,}2V \Rightarrow$ Ipotesi 1 Verificata.

Q_2 si trova nel punto di lavoro $I_{C2} = 2mA$, $V_{CE2} = 5V$ per cui il costruttore fornisce i seguenti valori tabulati

$$\begin{cases} h_{ie} = 4800 \\ h_{FE} = 290 \\ h_{fe} = 300 \end{cases} \qquad I_{B_2} = \frac{I_{C2}}{h_{FE}} = 6{,}8965517 \cdot 10^{-6} A$$

$V_{BE_2} = V_\gamma = 0{,}7V$ accettabile per lo standard delle tecnologie odierne.

$V_{BE_2} = V_{B2} - V_{E2} \Rightarrow V_{B2} = V_{BE2} + V_{E2} = 5{,}7V$

$I_9 = \frac{V_{B2}}{R_9} = 5 \cdot 10^{-4} A \qquad I_7 = -I_9 - I_{B2} = -5{,}06896551 \cdot 10^{-4} A$

$V_{B2} - V_K = I_7(R_7 + R_8) \Rightarrow V_K = V_{B2} - I_7(R_7 + R_8) = 12{,}03620 \, V$

$I_6 = \frac{V_{CC} - V_K}{R_6} = 2{,}9819 \cdot 10^{-3} A \qquad I_{D1} = I_6 + I_7 = 2{,}4750034 \cdot 10^{-3} A$

$V_K - V_{D1} = I_{D1} \cdot R_5 \Rightarrow V_{D1} = V_K - I_{D1} R_5 = 9{,}5611966 \, V$

Ipotesi 2: Q_1 in zona di saturazione $\Rightarrow I_{D1} = K(V_{GS_1} - V_T)^2$

$V_{GS1} = V_T \pm \sqrt{\frac{I_{D1}}{K}}$

Per la condizione di conduzione di Q_1, $V_{GS2} > V_T$, scelgo

$$V_{GS1} = V_T + \sqrt{\frac{I_{D1}}{k}} = 3,224861 \ V$$

$I_{G1} = 0 \Rightarrow I_{S1} = I_{D1}$

$$V_{G1} = V_{cc} \cdot \frac{R_4}{R_4 + R_3} = 8V$$

$$V_{S1} = V_{G1} - V_{GS1} = 4,775138 \ V$$

$V_{GS1} = V_{G1} - V_{S1}$

$$V_{S1} = I_{S1} \cdot R_2 \Rightarrow R_2 = \frac{V_{S1}}{I_{S1}} = 1929,34641 \ \Omega$$

$$V_{DS1} = V_{D1} - V_{S1} = 4,7860586 \ V$$

$V_{DS1} > V_{GS1} - V_T = 2,224 \ V \Rightarrow$ Saturazione di Q_1 verificata.

$\boxed{\text{PUNTI DI RIPOSO}}$

Q_1:

$I_{D1} = 2,475003 \ mA$

$V_{GS1} = 3,224861 \ V$

$V_{DS1} = 4,786058 V$

$g_m = 2k|V_{GS1} - V_T| =$

$= 2,224861 \cdot 10^{-3} V/A$

Q_2:

$I_{C2} = 2mA$

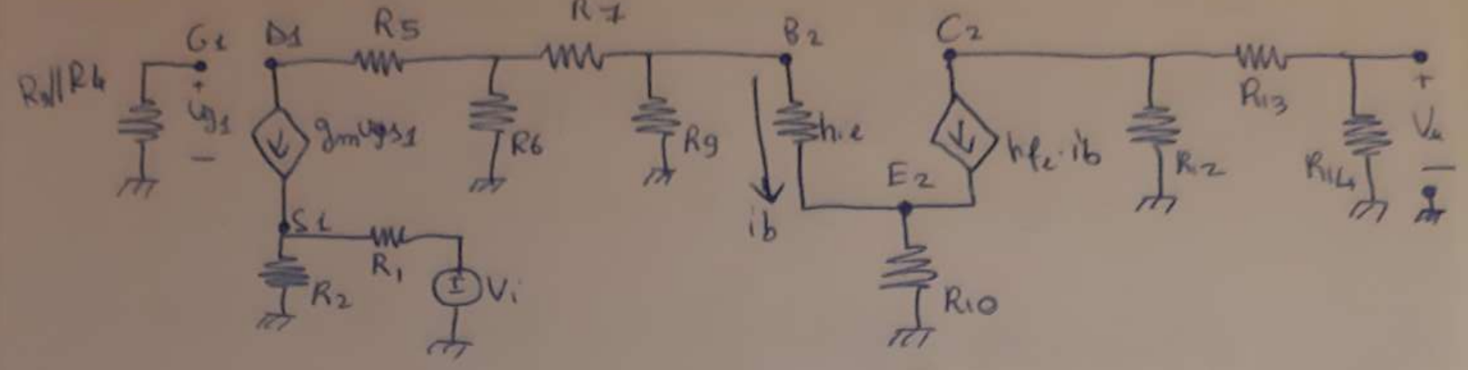
$V_{CE_2} = .5V$

$I_{B2} = 6,896551 \cdot 10^{-6} A$

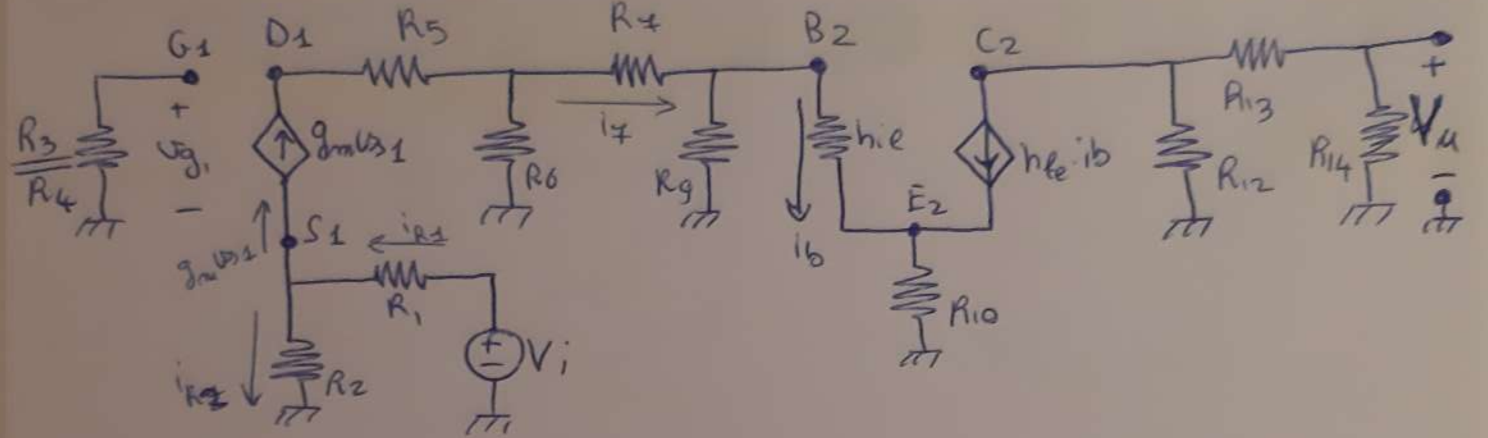
$h_{ie} = 4800 \ \Omega$

$h_{fe} = 300$

ESERCIZIO A) 2) Disegno il circuito per le variazioni:



$v_{g_1}=0 \Rightarrow g_m v_{gs_1} = g_m (v_{g_1} - v_{s_1}) = -g_m v_{s_1}$



$$V_u = -h_{fe} \cdot i_b \cdot \frac{R_{12}}{R_{12}+R_{13}+R_{14}} \cdot R_{14} = -i_b \cdot R_{eq_1}$$

$R_{eq_1} = 851063{,}82\ \Omega$ $\qquad R_v = h_{ie} + R_{10}(h_{fe}+1) = 125200\ \Omega$

$$i_b = i_7 \cdot \frac{R_9}{R_9+R_v} = i_7 \cdot R_{eq_2}$$

$R_9 // R_v = 1048{,}60908$

$R_{eq_2} = 0{,}08345534\ \Omega$

$$i_7 = g_m v_{s_1} \cdot \frac{R_6}{R_6+R_7+R_9//R_v} = g_m v_{s_1} \cdot R_{eq_3}$$

$R_{eq_3} = 0{,}15445744\ \Omega$ $\qquad v_{s_1} = R_2 \cdot i_{R_2}$

$$i_{R_2} = i_{R_1} - g_m v_{s_1} = \frac{v_{s_1}}{R_2} = \frac{V_i - V_{s_1}}{R_1} - g_m v_{s_1}$$

$$v_{s1}\left(\frac{1}{R_2}+\frac{1}{R_1}+g_m\right)=V_i\cdot\frac{1}{R_1}$$

$$v_{s1}=V_i\cdot\frac{\frac{1}{R_1}}{\frac{1}{R_2}+\frac{1}{R_1}+g_m}=V_i\cdot R_{eq_4}$$

$R_{eq_4}=0{,}87938487\ \Omega$

$$\frac{V_u}{V_i}=-g_m\cdot R_{eq_4}\cdot R_{eq_3}\cdot R_{eq_2}\cdot R_{eq_1}=-21{,}463$$

ESERCIZIO B

Riduco la funzione booleana data in forma minima:

$$Y = \overline{(A+D)}(\bar B + \bar C + E) + \bar A(\bar B D + D E) + \bar C(A\bar D + B\bar E)$$

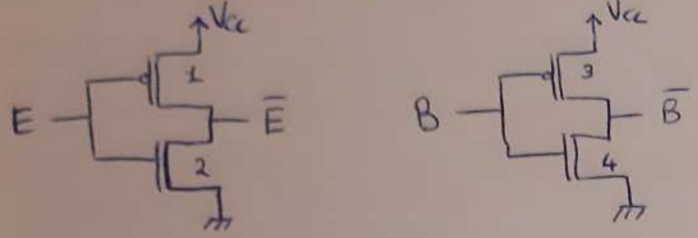
$$Y = (\bar A \cdot \bar D)(\bar B + \bar C + E) + \bar A \bar B D + \bar A D E + \bar C A \bar D + \bar C B \bar E$$

$$Y = \bar A \cancel{\bar D} \bar B + \bar A \cancel{\bar D} \bar C + \bar A \cancel{\bar D} E + \bar A \cancel{\bar B} D + \bar A \cancel{D} E + \bar C \cancel{A} \bar D + \bar C B \bar E$$

$$Y = \bar A \bar B + \bar C \bar D + \bar A E + \bar C B \bar E = \bar A(\bar B + E) + \bar C(\bar D + B\bar E)$$

Realizzabile con $N = 2 \cdot 7 + 2 \cdot 2 = 18$ mosfet.

Generatori di segnali negati:

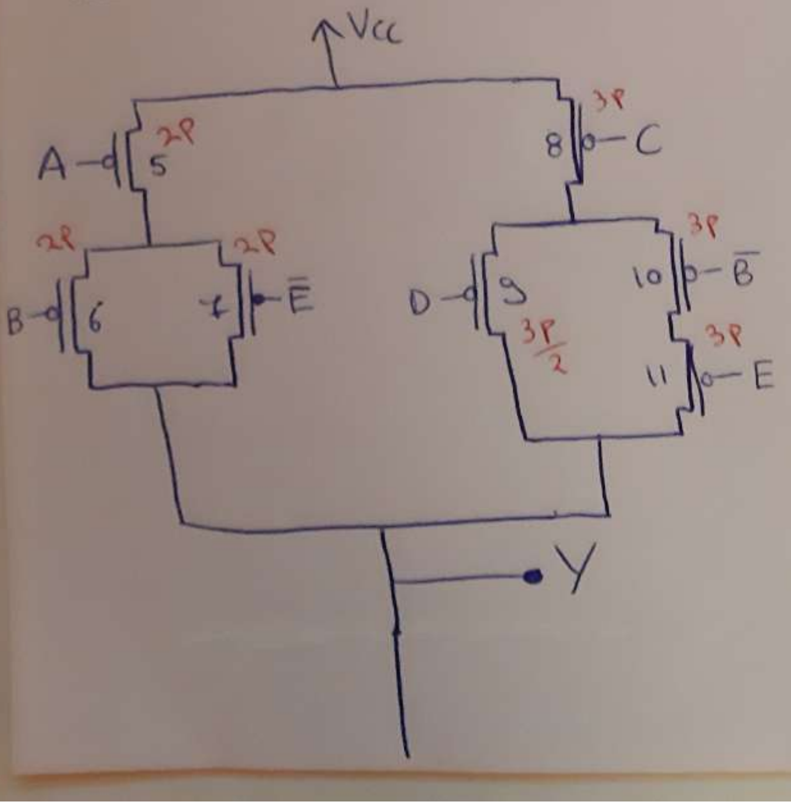


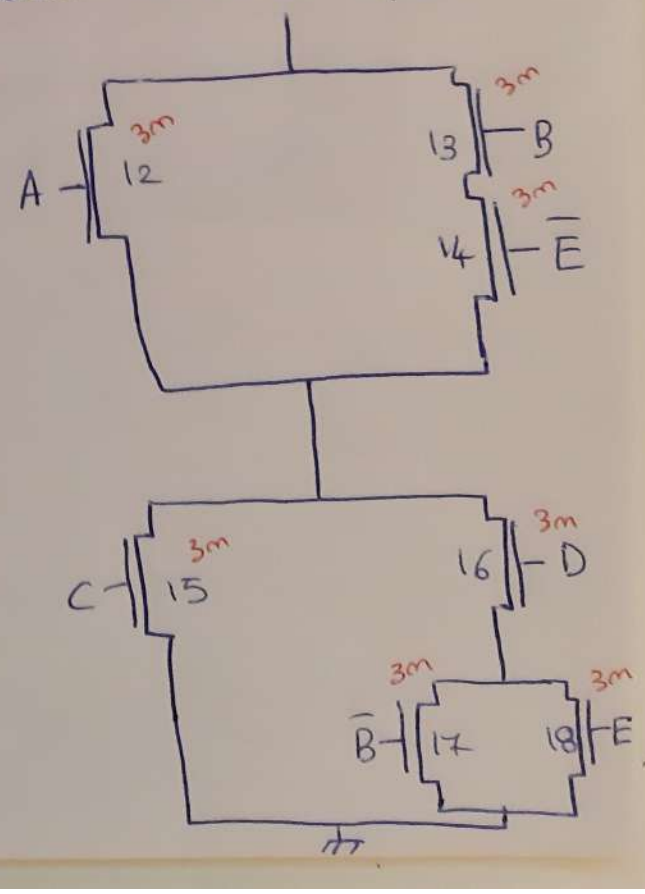
Inverter di base:

$$\left(\frac{W}{L}\right)_{1,3} = p = 5$$

$$\left(\frac{W}{L}\right)_{2,4} = n = 2$$

Disegno pullup network e pulldown network per simmetria:





$\boxed{\text{DIMENSIONAMENTO}}$ Pull-up Network: WORST CASE:

Conducono

$Q_8 - Q_{10} - Q_{11}$: $\Rightarrow$ $\left(\frac{W}{L}\right)_{8,10,11} = x \Rightarrow \frac{1}{x} + \frac{1}{x} + \frac{1}{x} = \frac{1}{p} \Rightarrow x = 3p = 15$

Conducono $Q_5 - Q_6$ oppure $Q_5 - Q_7$:

$\left(\frac{W}{L}\right)_{5,6,7} = y \Rightarrow \frac{1}{y} + \frac{1}{y} = \frac{1}{p} \Rightarrow y = 2p$

Conducono $Q_8 - Q_9$; di cui $\left(\frac{W}{L}\right)_8 = 3p$

$\left(\frac{W}{L}\right)_9 = f \Rightarrow \frac{1}{f} + \frac{1}{3p} = \frac{1}{p} \Rightarrow f = \frac{3p}{2}$

Pull-down Network: Il percorso $Q_{13} - Q_{14} - Q_{16} - Q_{17}$ non è possibile per la contemporanea presenza di B e $\overline{B}$ nella serie.

Il percorso $Q_{13} - Q_{14} - Q_{16} - Q_{18}$ non è possibile per la contemporanea presenza di $\overline{E}$ e E nella serie.

WORST CASE:

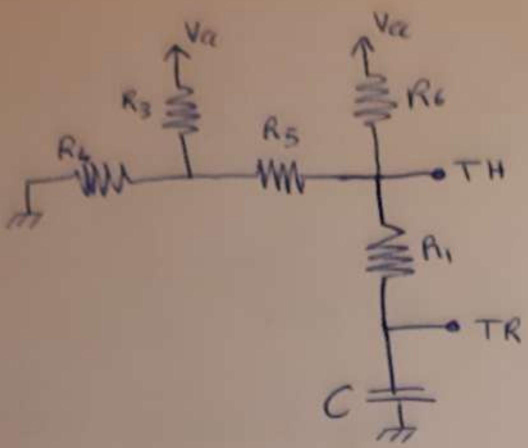
Conducono $Q_{13} - Q_{14} - Q_{15}$,
oppure $Q_{12} - Q_{16} - Q_{17}$,
oppure $Q_{12} - Q_{16} - Q_{18}$:

$\left(\frac{W}{L}\right)_{12,13,14,15,16,17,18} = z$

$\frac{1}{z} + \frac{1}{z} + \frac{1}{z} = \frac{1}{m}$

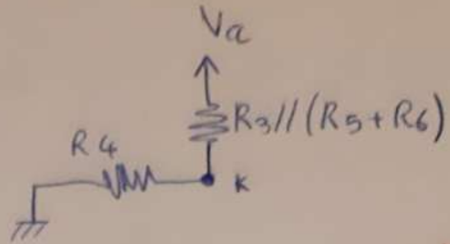
$z = 3m = 6$

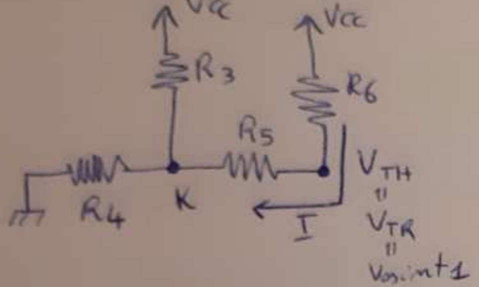
$\boxed{\text{ESERCIZIO C}}$ Q_1 N-MOS $\begin{cases} Q = 1 \\ D = \text{'HZ'} \end{cases}$ $V_{G1} = 0V$ $V_{GS1} = 0V$ $V_{S1} = 0V$ $V_{GS1} < V_T$



Q_1 OFF

$V_{i1} = \frac{1}{3} V_{cc} = 2V$



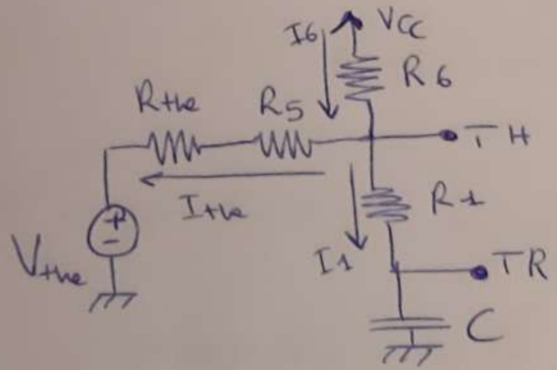


$$V_K = V_{cc} \cdot \frac{R_4}{\underbrace{R_4 + R_3 /\!/ (R_5 + R_6)}_{R_{eq1}}} = 3,75V$$

$$I = \frac{V_{cc} - V_K}{R_5 + R_6} = 3 \cdot 10^{-3} A$$

$$V_{osint1} = V_{cc} - R_6 \cdot I = 4,5V$$

$\boxed{V_{i1} < V_{comm1} < V_{osint1}}$ $\Rightarrow$ Ho effettivamente commutazione



$R_{the} = R_4 /\!/ R_3$

$V_{the} = V_{cc} \cdot \frac{R_4}{R_4 + R_3}$

$R_{The} = 750\ \Omega$

$V_{the} = \frac{3}{2} V$

$V_{TH} = \frac{2}{3} V_{cc} = 4V$

$$I_6 = \frac{V_{cc} - V_{TH}}{R_6}$$

$$I_{The} = \frac{V_{TH} - V_{The}}{R_{The} + R_5}$$

$$I_1 = I_6 - I_{The}$$

$$V_{comm1} = V_{TH} - I_1 \cdot R_1 = V_{TH} - (I_6 - I_{The}) R_1 =$$

$$= V_{TH} - \left(\frac{V_{cc} - V_{TH}}{R_6} - \frac{V_{TH} - V_{The}}{R_{The} + R_5} \right) R_1 = 3,4V$$

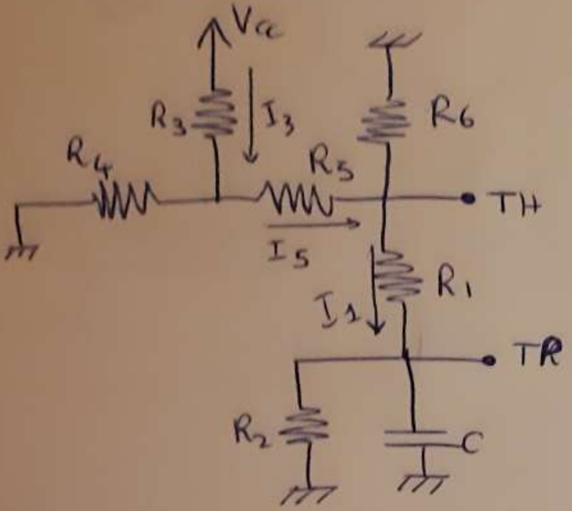
$$= 3,4V$$

$$R_{vc1} = R_1 + R_6 // [R_5 + R_3 // R_4] = 733,33333\ \Omega$$

$$\tau_1 = C \cdot R_{vc1} = 6,01333333 \cdot 10^{-4}\ s$$

$$T_1 = \tau_1 \cdot \ln\left(\frac{V_{i1} - V_{asint1}}{V_{comm1} - V_{asint1}}\right) = 4,93682972 \cdot 10^{-4}\ s$$

$$\begin{cases} Q=0 \\ D=0 \end{cases} \Rightarrow \begin{matrix} V_{G1} = 6V \\ V_{S1} = 0\,V \end{matrix} \Rightarrow V_{GS1} = 6V > V_T \Rightarrow Q_1\ ON$$



$$V_{i2} = V_{comm\,1} = 3,4V$$

$$V_{comm\,2} = V_{i1} = \frac{1}{3}V_{cc} = 2V$$

$$I_3 = \frac{V_{cc}}{R_3 + R_4 // (R_5 + [R_6 // (R_1 + R_2)])} = \frac{6\ V}{3343,283\ \Omega} = 1,79464 \cdot 10^{-3}\ A$$

$$I_5 = I_3 \cdot \frac{R_4}{R_4 + R_5 + R_6 // (R_1 + R_2)} = 0,6567164 \cdot 1,79464 \cdot 10^{-3} =$$

$$= 1,17856952 \cdot 10^{-3} A$$

$$\boxed{V_{i2} > V_{comm\,2} > V_{asint2}}$$

$$I_1 = I_5 \cdot \frac{R_6}{R_6 + R_1 + R_2} = 5,3371341 \cdot 10^{-4} A$$

$$R_{vc2} = R_2 // [R_1 + R_6 // (R_5 + R_3 // R_4)] = 157,142857\ \Omega$$

$$V_{asint2} = I_1 \cdot R_2 = 0,10714268$$

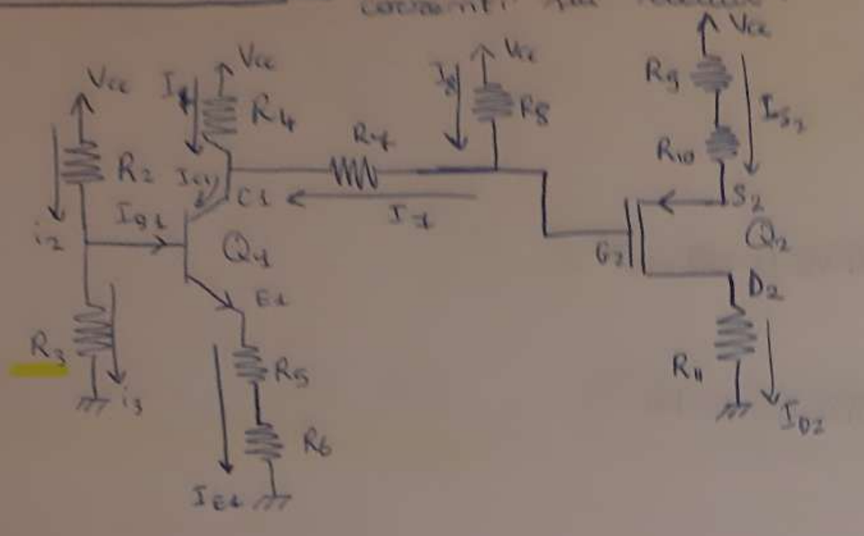
$$\tau_2 = C\, R_{vc2} = 1,288571 \cdot 10^{-4}\ s$$

$$T_2 = \tau_2 \cdot \ln\left(\frac{V_{i2} - V_{asint2}}{V_{comm2} - V_{asint2}}\right) = 7,13440994 \cdot 10^{-5}\ s$$

$$T = T_1 + T_2 = 5,65027 \cdot 10^{-4}\ s \qquad f = \frac{1}{T} = 1769,82\ Hz$$

Prova Scritta del 28 giugno 2018

ESERCIZIO A 1 Disegno il circuito in continua e disegno le correnti sui rami:



$V_{D2} = 7V$

$I_{D2} = \frac{V_{D2}}{R_{11}} = 2 \cdot 10^{-3} A$

$I_{G2} = 0 \Rightarrow I_{S2} = I_{D2}$

$V_{cc} - V_{S2} = I_{S2}(R_9 + R_{10})$

$V_{S2} = V_{cc} - I_{S2}(R_9 + R_{10}) = $

$= 12V$

Ipotesi 1: Q_2 in zona di saturazione: $I_{D2} = K(V_{GS2} - V_T)^2$

$$V_{GS2} = V_T \pm \sqrt{\frac{I_{D2}}{K}}$$

Per la condizione di conduzione di Q_2: $V_{GS2} < V_T$

$$V_{GS2} = V_T - \sqrt{\frac{I_{D2}}{K}} = -3V$$

$V_{DS2} = -5V$

$V_{DS2} < V_{GS2} - V_T = -4$

Ipotesi 1 verificata

$V_{GS2} = V_{G2} - V_{S2} \Rightarrow V_{G2} = V_{GS2} + V_{S2} = 9V$

$I_8 = \frac{V_{CC} - V_{G2}}{R_8} = 4 \cdot 10^{-4} A$ $\quad I_G = 0 \Rightarrow I_7 = I_8$

$V_{G2} - V_{C1} = I_7 \cdot R_7 \Rightarrow V_{C1} = V_{G2} - I_7 R_7 = 8V$

$I_4 = \frac{V_{CC} - V_{C1}}{R_4} = 1{,}6 \cdot 10^{-3} A$ $\quad I_{C1} = I_4 + I_7 = 2 \cdot 10^{-3} A$

Ipotesi 2: Q_1 in zona attiva diretta: $\Rightarrow I_{B1} \ll I_{C1} \Rightarrow I_{E1} = I_{C1}$

$V_{E1} = I_{E1} \cdot (R_5 + R_6) = 3V$ $\quad V_{CE1} = V_{C1} - V_{E1} = 5V$

$V_{CE1} \geq V_{CESAT} = 0{,}2V \Rightarrow$ Ipotesi 2 verificata.

Q_1 si trova nel punto di lavoro $I_C = 2mA$, $V_{CE} = 5V$ per cui il costruttore fornisce i seguenti valori tabellati

$$\begin{cases} h_{fe} = 300 \\ h_{ie} = 4800 \\ h_{FE} = 290 \end{cases}$$

$I_{B1} = \frac{I_{C1}}{h_{FE}} = 6{,}896551724 \cdot 10^{-6} A$

$V_{BE2} = V_{B2} - V_{E2}$

$V_{BE1} = V_\gamma = 0{,}7V$ per gli standard delle tecnologie odierne.

$V_{B1} = V_{BE1} + V_{E1} = 3{,}7 V$

$I_2 = \frac{V_{CC} - V_{B1}}{R_2} = 5 \cdot 10^{-5} A$

$I_3 = I_2 - I_{B2} = 4{,}310344828 \cdot 10^{-5} A$

$R_3 = \frac{V_{B1}}{I_3} = 85840 \,\Omega$

PUNTI DI RIPOSO

Q 2:

$I_{D2} = 2mA$

$V_{GS2} = -3V$

$V_{DS2} = -5V$

$g_m = 2K |V_{GS} - V_T| =$
$= 2 \cdot 10^{-3} A/V$

Q1:

$I_{C1} = 2mA$

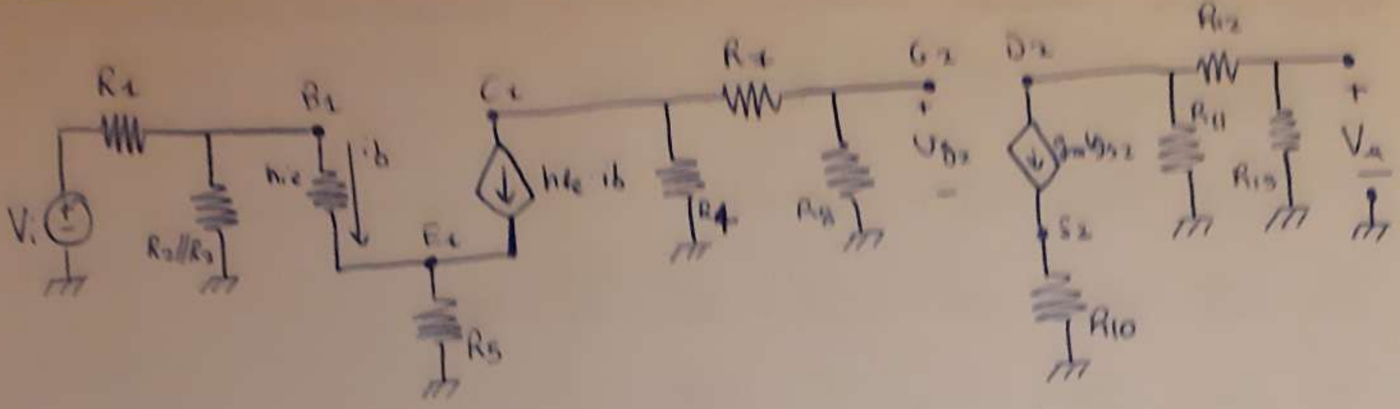
$V_{CE1} = 5V$

$I_{B1} = 6{,}8965517 \cdot 10^{-6} A$

$h_{fe} = 300$

$h_{ie} = 4800 \,\Omega$

ESERCIZIO A) 2) Disegno il circuito per le variazioni



$$V_u = -g_m v_{gs2} \cdot \frac{R_{11}}{R_{11}+R_{12}+R_{13}} \cdot R_{13} = -g_m v_{gs2} \cdot R_{eq1}$$

$R_{eq1} = 2333,3333\ \Omega$

$$v_{gs2} = v_{g2} - v_{s2} = v_{g2} - g_m v_{gs2} \cdot R_{10} \Rightarrow v_{gs2} = \frac{v_{g2}}{1+g_m R_{10}}$$

$$v_{g2} = -h_{fe} \cdot i_b \cdot \frac{R_4}{R_4+R_7+R_8} \cdot R_8 = -h_{fe} \cdot i_b \cdot R_{eq2}$$

$R_v = h_{ie} + R_5(h_{fe}+1) = 65000\ \Omega$

$R_{eq2} = 4500\ \Omega$

$$i_b = V_i \cdot \frac{R_2//R_3//R_v}{R_2//R_3//R_v + R_1} \cdot \frac{1}{R_v} = V_i \cdot R_{eq3}$$

$R_2//R_3//R_v = 32753,91709\ \Omega$

$R_{eq3} = 1,4928827 \cdot 10^{-5}\ \Omega$

$$\frac{V_u}{V_i} = -g_m \cdot \frac{-h_{fe} \cdot R_{eq3} \cdot R_{eq2}}{1+g_m R_{10}} \cdot R_{eq1} = 47,0258$$

$\boxed{\text{ESERCIZIO B}}$

Riduco la funzione booleana data in forma minima:

$$Y = \overline{\bar{D}E}\,(\bar{A}B + \bar{C}\bar{B}) + \bar{C}(\bar{B}\bar{D} + \bar{E}) + \bar{A}BC$$

$$Y = (D + \bar{E})(\bar{A}B + \bar{C}\bar{B}) + \bar{C}\bar{B}\bar{D} + \bar{C}\bar{E} + \bar{A}BC$$

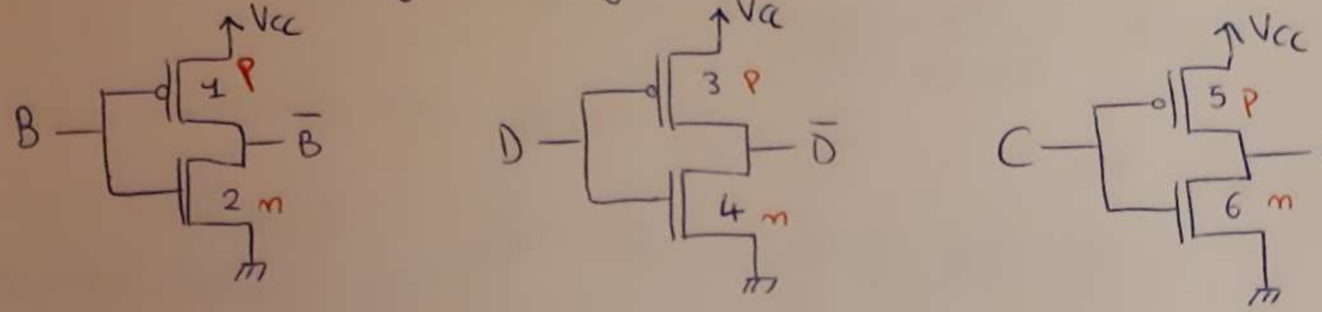
$$Y = D\bar{A}\cancel{B} + \bar{E}\cancel{\bar{A}}B + D\cancel{\bar{C}}\bar{B} + \bar{E}\cancel{\bar{C}}\bar{B} + \cancel{\bar{C}}\bar{B}\bar{D} + \cancel{\bar{C}}\bar{E} + \cancel{\bar{A}}BC$$

$$Y = D\cancel{\bar{A}B} + \bar{E}\cancel{\bar{A}}B + \bar{C}\bar{B} + \bar{C}\bar{E} + \bar{A}\cancel{B}C$$

$$Y = \bar{A}B(D + \bar{E} + C) + \bar{C}(\bar{B} + \bar{E})$$

Realizzabile con $N = 2 \cdot 8 + 2 \cdot 3 = 22$ mosfet.

Generatori di segnali negati:

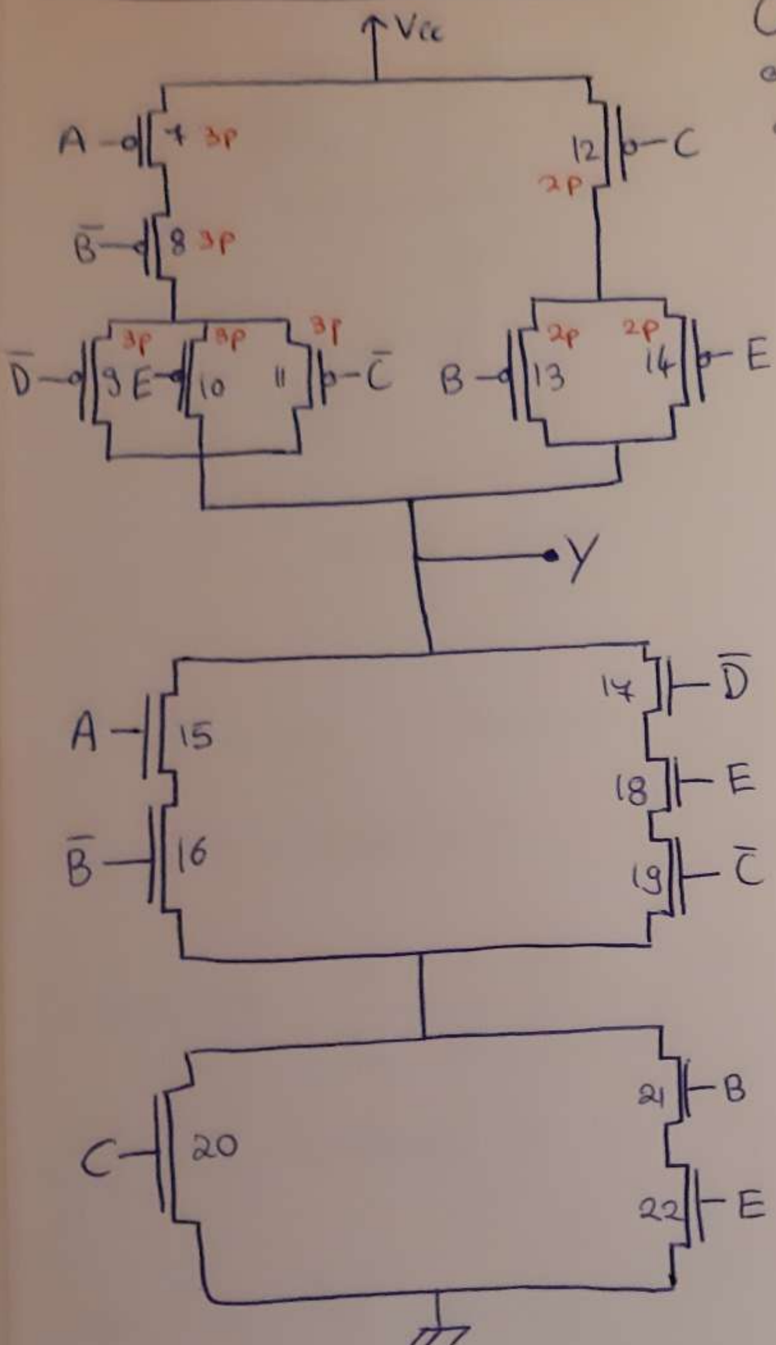


Inverter di base:

$$\left(\frac{W}{L}\right)_{1,3,5} = p = 5$$

$$\left(\frac{W}{L}\right)_{2,4,6} = n = 2$$

Disegno pull-up network e per simmetria ottengo la pull-down network:



DIMENSIONAMENTO

PUN WORST CASE:

Conducono $Q_7 - Q_8 - Q_9$,
oppure $Q_7 - Q_8 - Q_{10}$,
oppure $Q_7 - Q_8 - Q_{11}$:

$$\left(\frac{W}{L}\right)_{7,8,9,10,11} = X$$

$$\frac{1}{X} + \frac{1}{X} + \frac{1}{X} = \frac{1}{p} \Rightarrow X = 3p = 15$$

Conducono $Q_{12} - Q_{13}$,
oppure $Q_{12} - Q_{14}$:

$$\left(\frac{W}{L}\right)_{12,13,14} = Y$$

$$\frac{1}{Y} + \frac{1}{Y} = \frac{1}{p} \Rightarrow Y = 2p = 10$$

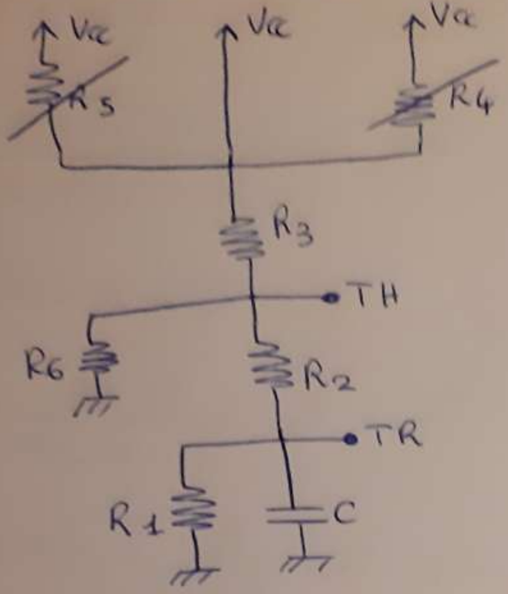
PDN

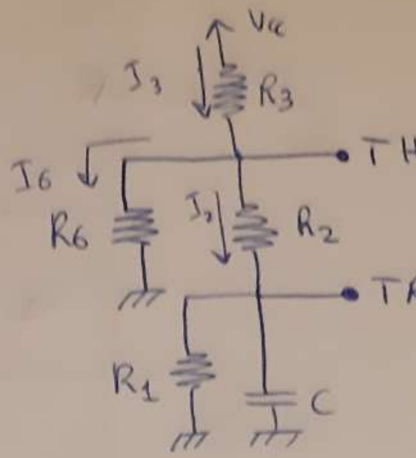
ESERCIZIO C

Q_1 NMOS
Q_2 PMOS

$\begin{cases} Q = 1 \\ D = 'HZ \end{cases} \Rightarrow$ $V_{G1} = 6V$, $V_{S1} = 0V$, $V_{GS1} = 6V \Rightarrow V_{GS1} > V_{T_1} \Rightarrow Q_1$ ON

$V_{G2} = 0V$, $V_{S2} = 6V$, $V_{GS2} = -6V \Rightarrow V_{GS2} < V_{T_2} \Rightarrow Q_2$ ON





$V_{i1} = \frac{1}{3} V_{cc} = 2V$ $\quad V_{asint1} = V_{TH} \cdot \frac{R_1}{R_1 + R_2} = V_{TH}\, R_{eq_1} = 4{,}3199V$

$R_{eq_1} = 0{,}9782608\ \Omega$ $\quad R_6 // (R_2 + R_1) = 557{,}575757\ \Omega$

$V_{TH} = V_{cc} \cdot \frac{R_6 // (R_2 + R_1)}{R_3 + R_6 // (R_2 + R_1)} = V_{cc} \cdot R_{eq_2} = 4{,}4159994\ V$

$R_{eq_2} = 0{,}73599999\ \Omega$ $\quad V_{commut1} = V_{TH} - I_2 \cdot R_2 = 3{,}8V$

$V_{TH} = \frac{2}{3} V_{cc} = 4V$

$I_2 = I_3 - I_6 =$

$= \frac{V_{cc} - V_{TH}}{R_3} - \frac{V_{TH}}{R_6} = 5 \cdot 10^{-3} A$

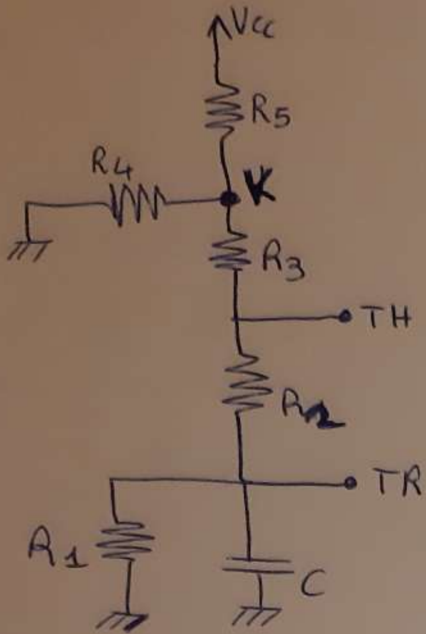
$\boxed{V_{i1} < V_{commut1} < V_{asint1}}$

ho effettivamente commutazione.

$R_{VC1} = R_1 // [R_2 + (R_6 // R_3)] = 180\ \Omega$ $\quad \tau_1 = C \cdot R_{VC1} = 8{,}46 \cdot 10^{-6}\ s$

$T_1 = \tau_1 \cdot \ln\left(\frac{V_{i1} - V_{asint1}}{V_{commut1} - V_{asint1}}\right) = 1{,}265187 \cdot 10^{-5}\ s$

$\begin{cases} Q=0 \\ D=0 \end{cases} \Rightarrow \begin{array}{l} V_{G2} = 0V,\ V_{S2} = 6V,\ V_{GS2} = 0V > V_{T2} \Rightarrow Q_2 \text{ OFF} \\ V_{G1} = 0V,\ V_{S1} = 0V,\ V_{GS1} = 0V < V_{T1} \Rightarrow Q_1 \text{ OFF} \end{array}$



$V_{i2} = V_{comm\,1} = 3{,}8\,V$

$V_{comm\,2} = V_{i1} = \frac{1}{3} V_{cc} = 2V$

$$V_K = V_{cc} \cdot \frac{R_4 /\!/ (R_3 + R_2 + R_1)}{R_5 + R_4 /\!/ (R_3 + R_2 + R_1)} =$$

$$= 6 \cdot 0{,}34 = 2{,}04\,V$$

$$V_{TH} = V_K \cdot \frac{R_2 + R_1}{R_3 + R_2 + R_1} = 1{,}84\,V$$

$$V_{osint\,2} = V_{TH} \cdot \frac{R_1}{R_1 + R_2} = 1{,}8\,V$$

$\boxed{V_{i2} > V_{comm\,2} > V_{osint\,2}}$

Ho effettivamente la commutazione.

$R_{vc2} = R_1 /\!/ [R_2 + R_3 + R_4 /\!/ R_5] = 720\,\Omega$

$\tau_2 = C \cdot R_{vc2} = 3{,}384 \cdot 10^{-5}\,s$

$T_2 = \tau_2 \cdot \ln\left(\frac{V_{i2} - V_{osint2}}{V_{comm\,2} - V_{osint2}}\right) = 7{,}791947 \cdot 10^{-5}\,s$

$T = T_1 + T_2 = 9{,}0571346 3 \cdot 10^{-5}\,s$

$f = \frac{1}{T} = 11041{,}019\ Hz$