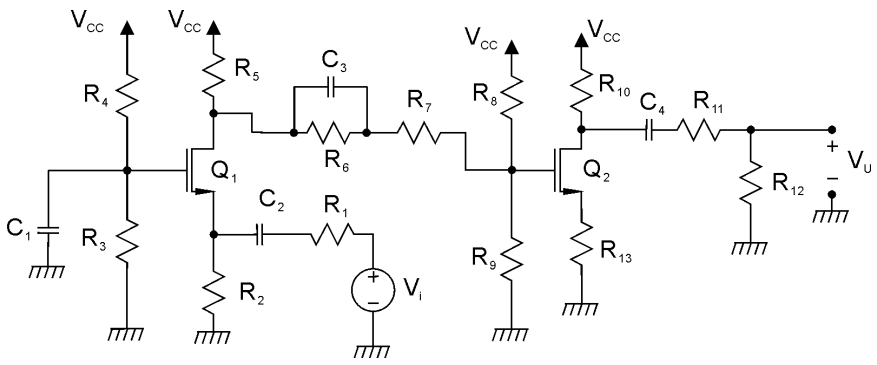
ELETTRONICA DIGITALE

Corso di Laurea in Ingegneria Informatica

Prova scritta del 20 luglio 2017

Esercizio A

R_1 =50 Ω	R_{11} = 500 Ω
R_2 = 8 kΩ	R_{12} = 10 kΩ
R_3 = 10 kΩ	R_{13} = 1.5 kΩ
R_4 = 20 kΩ	C_1 = 1 μF
R_5 = 8 kΩ	C_2 = 8.2 nF
R_7= 500 Ω	C_3= 5.6 nF
R_8 = 24 kΩ	C_4= 100 nF
R_9 = 6 kΩ	V_{CC} = 18 V
R_{10} = 4 kΩ	



Q_1 e Q2 sono transistori MOS a canale n resistivi, con la corrente di drain in saturazione data da $I_D=k(V_{GS}-V_T)^2$ con k = 0.5 mA/V^2 e V_T = 1 V;

Con riferimento al circuito in figura:

1) Calcolare il valore della resistenza R_6 in modo che, in condizioni di riposo, la tensione sul drain di Q_2 sia 10 V. Determinare, inoltre, il punto di riposo dei due transistori e verificarne la saturazione. (R: R_6 = 7500 Ω)
2) Determinare l'espressione e il valore di V_U/Vi alle frequenze per le quali C_1, C_2, C_3 e C_4 possono essere considerati dei corto circuiti. (R: V_U/Vi = - 3.77)
3) (**Solo per 12 CFU**) Determinare la funzione di trasferimento V_U/V_i e tracciarne il diagramma di Bode quotato asintotico del modulo. (R: $f_{z1}=f_{p1}$; f_{z2}=0 Hz; f_{p2}=20672 Hz; f_{z3}=3789 Hz; f_{p3}=5926 Hz; f_{z4}=0 Hz; f_{p4}=110 Hz)

Esercizio B

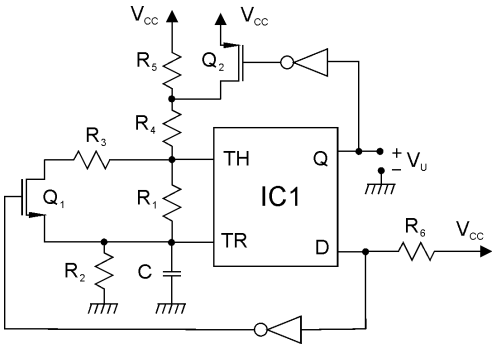
Progettare una porta logica in tecnologia CMOS, utilizzando la tecnica della pull-up network e della pull-down network, che implementi la funzione logica:

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

Determinare il numero dei transistori necessari e disegnarne lo schema completo. Dimensionare inoltre il rapporto (W/L) di tutti i transistori, assumendo, per l'inverter di base, W/L pari a 2 per il MOS a canale *n* e pari a 5 per quello a canale *p*. Si specifichino i dettagli della procedura di dimensionamento dei transistori.

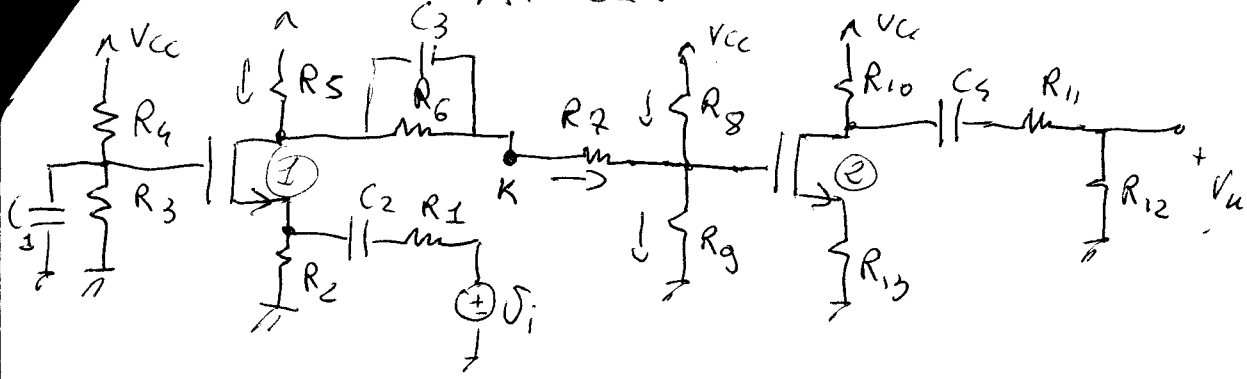
Esercizio C

R_1 =200 Ω	R_5 = 24.16 kΩ
R_2 = 5 kΩ	R_6 = 1 kΩ
R_3 = 50 Ω	C = 940 pF
R_4 = 800 Ω	**V_{CC} = 6 V**



Il circuito IC_1 è un NE555 alimentato a **V_{CC} = 6V**, Q_1 ha una R_{on} = 0 e V_T = 1V e Q_2 una R_{on} = 0 e V_T = -1V, gli inverter sono ideali. Determinare la frequenza del segnale di uscita del multivibratore in figura. (R: f = 242027 Hz)

APPELLO 20/07/2017



$R_1 = 50\,\Omega$
$R_2 = 8\,k\Omega$
$R_3 = 10\,k\Omega$
$R_4 = 20\,k\Omega$
$R_5 = 8\,k\Omega$
$R_6 = 500\,\Omega$
$R_8 = 24\,k\Omega$
$R_9 = 6\,k\Omega$
$R_{10} = 4\,k\Omega$
$R_{11} = 500\,\Omega$
$R_{12} = 10\,k\Omega$
$R_{13} = 1.5\,k\Omega$
$C_1 = 1\,\mu F$
$C_2 = 8.2\,nF$
$C_3 = 5.6\,nF$
$C_4 = 100\,nF$
$V_{CC} = 18\,V$
$K_1 = K_2 = 0.5\,\frac{mA}{V^2}$

Det R_6 per $V_{D2} = 10\,V$

$$I_{D2} = \frac{V_{CC} - V_{D2}}{R_{10}} = 2\,mA$$

$I_G = 0 \Rightarrow I_{S2} = I_{D2} = 2\,mA$

$V_{S2} = I_{S2} \cdot R_{13} = 3\,V$

hp: Q_2 SATURO $\Rightarrow I_{D2} = K_2 (V_{GS2} - V_{T2})$

$$\Rightarrow V_{GS2} = V_{T2} \oplus \sqrt{\frac{I_{D2}}{K_2}} = 3\,V$$

$V_{DS2} = 10 - 3 = 7\,V > V_{GS2} - V_{T2} = 2\,V \Rightarrow$ hp SAT2 OK

$V_{G2} = V_{GS2} + V_{S2} = 3 + 3 = 6\,V$

$$I_8 = \frac{V_{CC} - V_{G2}}{R_8} = 0.5\,mA$$

$$I_9 = \frac{V_{G2}}{R_9} = 1\,mA$$

$I_7 = I_9 - I_8 = 0.5\,mA$

$V_K = V_{G2} + R_7 I_7 = 6.25\,V$

$I_{G1} = 0 \Rightarrow$

$$V_{G1} = \frac{V_{CC} R_3}{R_3 + R_4} = 6\,V$$

hp: Q_1 SATURO $\Rightarrow I_{D1} = K_1 (V_{GS1} - V_{T1})^2$

$$I_{D1} = K_1 (V_{G1} - R_2 I_{D1} - V_{T1})^2 = 0.5 \times 10^{-3} (6 - 8 \times 10^3 I_{D1} - 1)^2 =$$

$$= 0.5 \times 10^{-3} (5 - 8 \times 10^{+3} I_{D1})^2 =$$

$$= 0.5 \times 10^{-3} (25 + 64 \times 10^{+6} I_{D1}^2 - 80 \times 10^{+3} I_{D1})$$

$$g_{m2} = 2K_2 (V_{GS2} - V_{T2}) = 2 \times 10^{-3}\,\frac{A}{V}$$

Q_2: $\begin{cases} I_{D2} = 2\,mA \\ V_{DS2} = 7\,V \\ V_{GS2} = 3\,V \\ g_{m2} = 2 \times 10^{-3}\,\frac{A}{V} \end{cases}$

$V_{GS1} = 12.5 \times 10^{-3} + 32 \times 10^{3} I_D^2 - 40 I_{D1}$

$(32 \times 10^3) I_D^2 - 41 I_{D1} + 12.5 \times 10^{-3} = 0$

$I_{D1} = \dfrac{41 \pm \sqrt{1681 - 1600}}{64 \times 10^3} = \dfrac{41 \pm 9}{64 \times 10^3} = \begin{cases} 0.78125 \text{ mA} \\ 0.5 \text{ mA} \end{cases}$

Per $I_{D1} = 0.78125$ mA si ha $V_S = 6.25 \Rightarrow V_{GS} = -0.25 < V_T \Rightarrow$ NON ACC.

$I_{D1} = 0.5$ mA

$V_{S1} = R_2 I_{D1} = 4$ V

$V_{GS1} = 6 - 4 = 2$ V $> V_T$ sol. OK

$I_S = I_{D1} + I_7 = 1$ mA

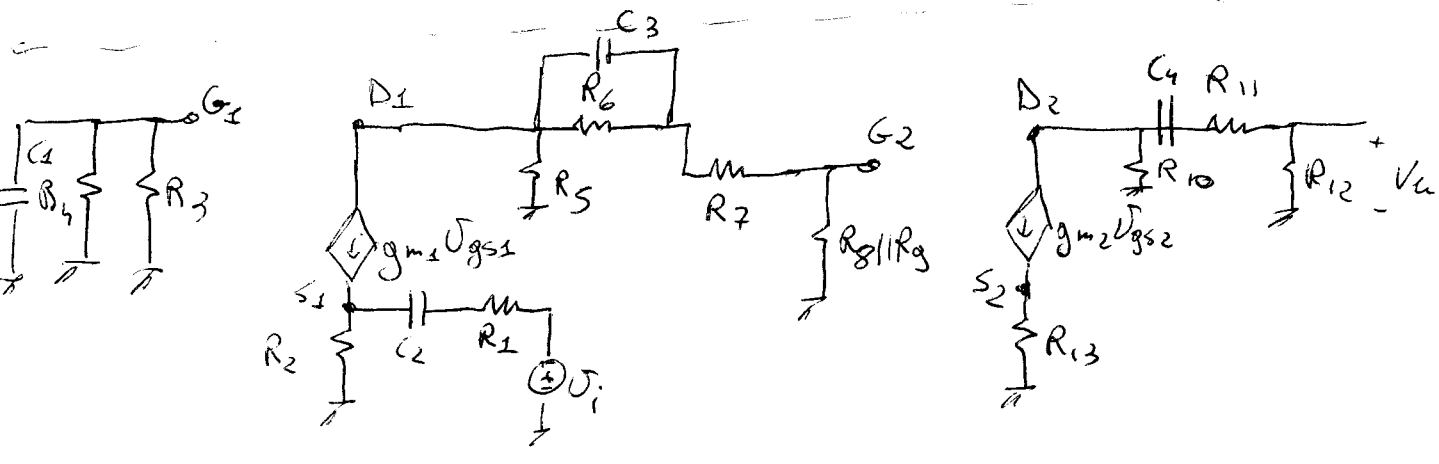
$V_{D1} = V_{CC} - R_5 I_S = 10$ V

$V_{DS1} = 10 - 4 = 6$ V $> V_{GS1} - V_{T1} = 1$ V $\Rightarrow$ hp. SATURO OK

$R_6 = \dfrac{V_{D1} - V_K}{I_7} = 7500\ \Omega$

Q_1: $\begin{cases} I_{D1} = 0.5 \text{ mA} \\ V_{DS1} = 6 \text{ V} \\ V_{GS1} = 2 \text{ V} \\ g_{m1} = 10^{-3} \dfrac{A}{V} \end{cases}$

$g_{m1} = 2K_1 (V_{GS1} - V_{T1}) = 10^{-3} \dfrac{A}{V}$



$V_u = (-g_{m2} v_{gs2}) \dfrac{R_{10}}{R_{10} + R_{11} + R_{12}} \cdot R_{12}$

$V_{S2} = R_{13} g_{m2} v_{gs2}$

$V_{gs2} = v_{g2} - g_{m2} R_{13} v_{gs2} \Rightarrow v_{GS2} = \dfrac{v_{g2}}{1 + g_m R_{13}}$

$$v_2 = \left(-g_{m1} v_{gs1}\right) \frac{R_5 \cdot (R_8 \| R_9)}{R_5 + R_7 + R_8 \| R_9}$$

$v_{G1} = \phi$

$$v_{S1} = v_i \frac{1}{R_1 + \left(R_2 \| \frac{1}{g_{m1}}\right)} \cdot \left(R_2 \| \frac{1}{g_{m1}}\right) = v_i \frac{\frac{R_2 \cdot \frac{1}{g_{m1}}}{R_2 + \frac{1}{g_{m1}}}}{R_1 + \frac{R_2 \frac{1}{g_{m1}}}{R_2 + \frac{1}{g_{m1}}}} =$$

$$= v_i \frac{\frac{R_2}{1 + g_{m1} R_2}}{\frac{(1 + g_{m1} R_2) R_1 + R_2}{1 + g_{m1} R_2}} = v_i \frac{R_2}{R_2 + R_1 (1 + g_{m1} R_2)}$$

$$\frac{v_u}{v_i} = \left(-g_{m2}\right) \frac{R_{10} R_{12}}{R_{10} + R_{11} + R_{12}} \cdot \frac{1}{1 + g_{m2} R_{13}} \cdot \left(-g_{m1}\right) \frac{R_5 \cdot R_8 \| R_9}{R_5 + R_7 + R_8 \| R_9} \cdot (-) \frac{R_2 \| \frac{1}{g_{m1}}}{R_1 + \left(R_2 \| \frac{1}{g_{m1}}\right)} =$$

(2×10^{-3}; $R_{10} R_{12} / (R_{10} + R_{11} + R_{12}) = 2758.62$; 0.25; 10^{-3}; 2887.218; 0.9461)

$$= -3.77 \qquad \left(|A_{CS}|_{dB} = 11.52\right)$$

C_1: $f_{z1} = f_{p1}$

C_2: $f_{z2} = \phi$ Hz

$$f_{p2} = \frac{1}{2\pi C_2 R_{v2}} = 20672.46 \text{ Hz}$$

$$R_{v2} = R_1 + \left(R_2 \| \frac{1}{g_{m1}}\right) = 938.\overline{8}\ \Omega$$

C_3: $f_{z3} = \frac{1}{2\pi C_3 R_6} = 3789.4$ Hz

$$f_{p3} = \frac{1}{2\pi C_3 R_{v3}} = 5926.285 \text{ Hz}$$

$$R_{v3} = R_6 \| [R_5 + R_7 + R_8 \| R_9] = 4295.623\ \Omega$$

C_4: $f_{z4} = \phi$ Hz

$$f_{p4} = \frac{1}{2\pi C_4 R_{v4}} = 109.76 \text{ Hz}$$

$$R_{v4} = R_{10} + R_{11} + R_{12} = 14500\ \Omega$$

ESERCIZIO B

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

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

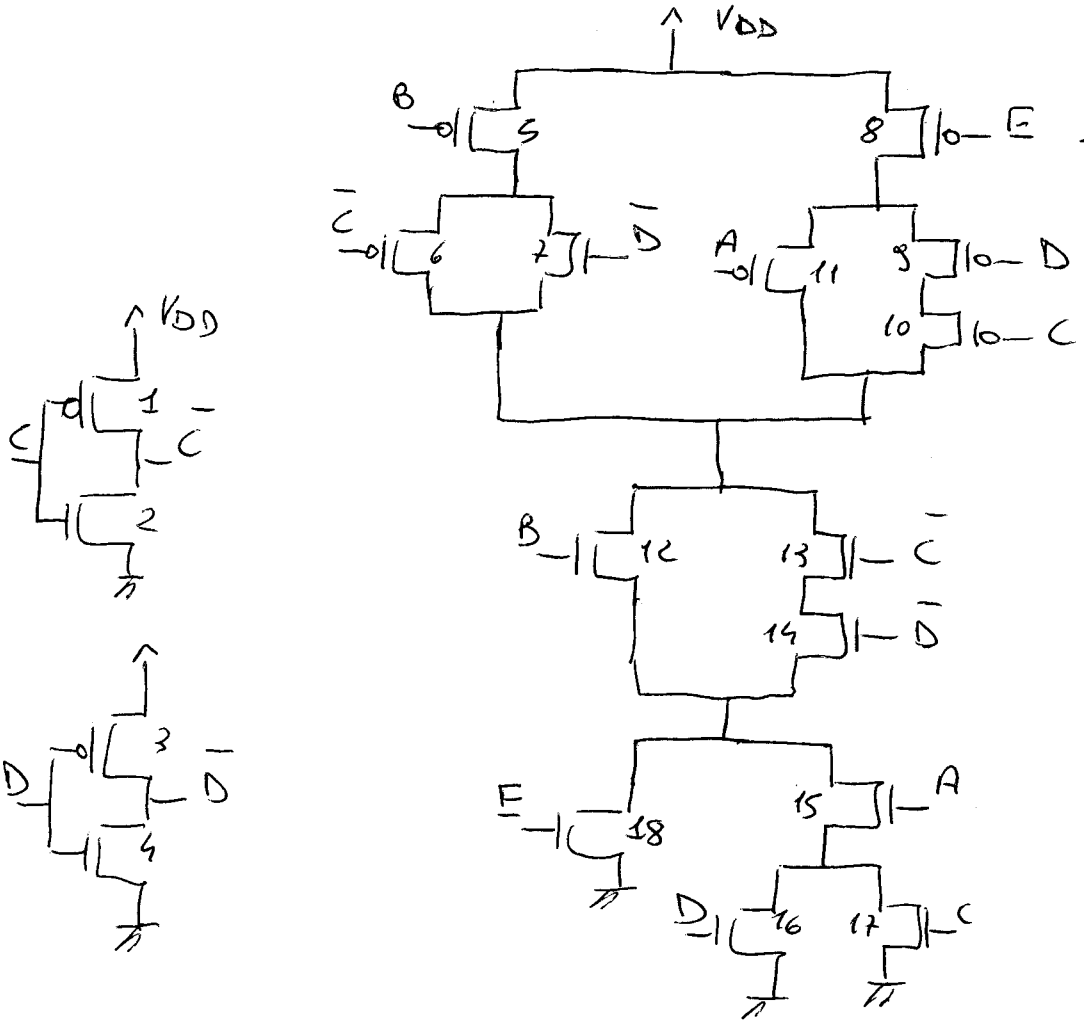
$$= \bar{A}\bar{B}C + \bar{A}\bar{C}\bar{E} + \bar{B}C\bar{D} + \bar{C}\bar{D}\bar{E} + A\bar{B}C + \bar{A}C\bar{E} + \bar{B}D =$$

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

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

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

N MOSFET = 18



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

PUN: $Q_8 - Q_9 - Q_{10} \Rightarrow \left(\frac{W}{L}\right)_{8,9,10} = 3p = 15$

$Q_8 - Q_{11}$: $\frac{1}{x} + \frac{1}{3p} = \frac{1}{p} \Rightarrow x = 1.5p = 7.5$

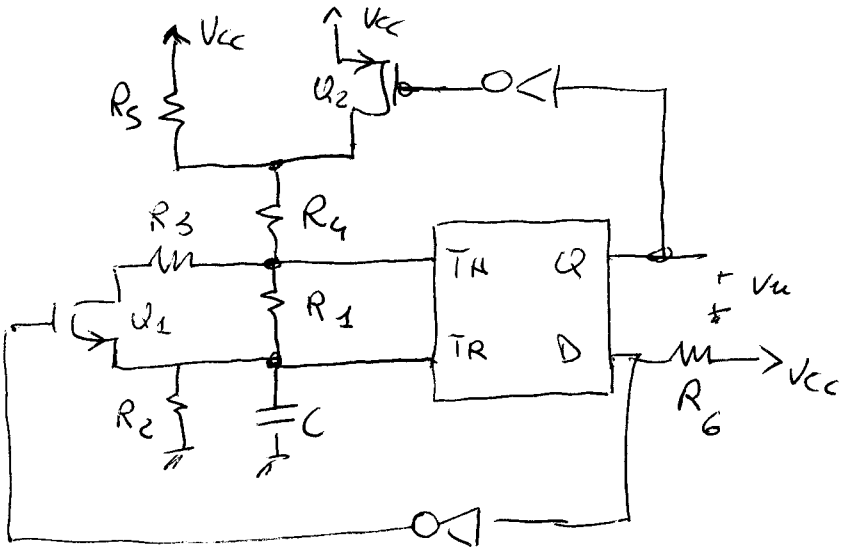
$\left.\begin{matrix} Q_5 - Q_6 \\ Q_5 - Q_7 \end{matrix}\right\} \Rightarrow \left(\frac{W}{L}\right)_{5,6,7} = 2p = 10$

PDN:

$Q_{13} - Q_{14} - Q_{15} - Q_{16}$ IMPOSSIBILE

$Q_{13}\ Q_{14} - Q_{15} - Q_{17}$ IMPOSSIBILE

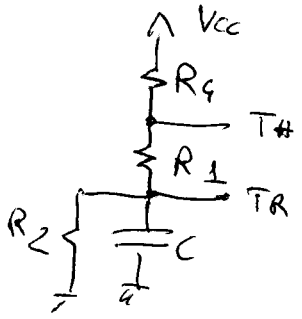
$\left.\begin{matrix} Q_{12} - Q_{15} - Q_{12} \\ Q_{12} - Q_{15} - Q_{16} \\ Q_{13} - Q_{14} - Q_{18} \end{matrix}\right\} = \left(\frac{W}{L}\right)_{12,13,14,15,16,17,18} = 3n = 6$



$R_1 = 200\ \Omega$
$R_2 = 5\ K\Omega$
$R_3 = 50\ \Omega$
$R_4 = 800\ \Omega$
$R_5 = 24.16\ K\Omega$
$R_6 = 1\ K\Omega$
$C = 940\ pF$
$V_{cc} = 6V$

- 1ª FASE:

$Q = 1$ } $V_{G1} = 0\ V$ $V_{S1} \geq 2V$ $V_{GS1} \leq -2V$ => Q_1 OFF
$D = HI$ } $V_{G2} = 0V$ $V_{S2} \cong 6V$ $V_{GS2} = -6V < V_{T2} = -1V$ => Q_2 ON



$V_{i1} = 2V$

$V_{f1} = V_{cc} \dfrac{R_2}{R_1 + R_2 + R_4} = 5V$

$V_{TH} = 4V$

$I_1 = \dfrac{V_{cc} - V_{TH}}{R_4} = 2.5\ mA$

$V_{com1} = V_{TH} - R_1 I_1 = 3.5V$

$V_{i1} < V_{com1} < V_{f1}$

$2V < 3.5V < 5V$ => OK

$R_{VC} = R_2 \,//\, [R_1 + R_4] \cong 833.\overline{3}\ \Omega$

$\tau_1 = R_{VC} \cdot C = 7.8\overline{3} \times 10^{-7}\ s$

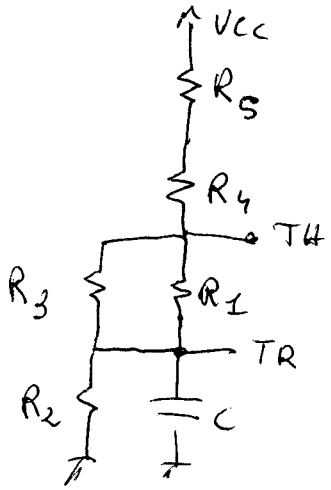
$T_1 = \tau_1 \ln\left(\dfrac{V_{i1} - V_{f1}}{V_{com1} - V_{f1}}\right) = 5.42965 \times 10^{-7}\ s$

FASE

$Q = \phi$
$D = \phi$
$\Rightarrow$

$V_{G1} = 6V \quad V_{S1} \leq V_{con1} = 3.5V \Rightarrow V_{GS1} \geq 2.5V \Rightarrow Q_1$ ON

$V_{G2} = 6V \quad V_{S2} = 6V \Rightarrow V_{GS2} = \phi V > V_{T2} \Rightarrow Q_2$ OFF



$V_{i2} = V_{con1} = 3.5V$

$V_{f2} = V_{i1} = 2V$

$$V_{f2} = V_{CC} \frac{R_2}{R_4 + R_5 + (R_1 \| R_3) + R_2} = 1V$$

$V_{i2} > V_{con2} > V_{f2}$

$3.5V > 2V > 1V$ (OK)

$R_{v2} = R_2 \| [(R_1 \| R_3) + R_4 + R_5] = 4166.\bar{6}\ \Omega$

$\tau_2 = R_{v2} \cdot C = 3.9166\ \mu s$

$T_2 = \tau_2 \ln\left(\frac{V_{i2} - V_{f2}}{V_{con2} - V_{f2}}\right) = 3.58880\ \mu s$

$T = T_1 + T_2 = 4.13172\ \mu s$

$f = \frac{1}{T} = 242026.99\ Hz$