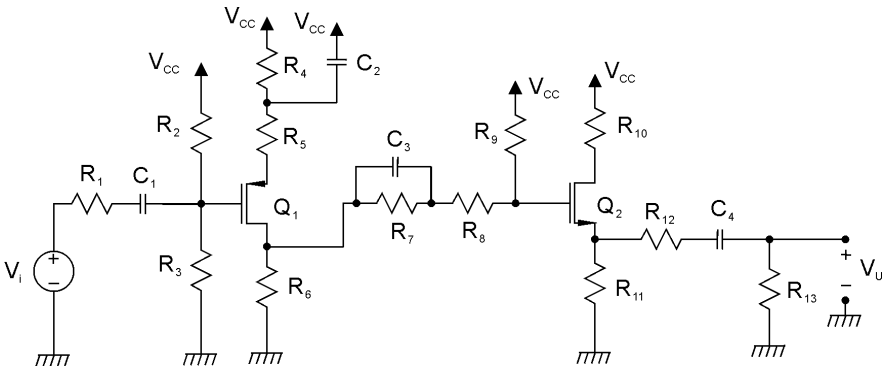
ELETTRONICA DIGITALE

Corso di Laurea in Ingegneria Informatica

Prova scritta del 06 giugno 2019

Esercizio A

R_1 = 200 Ω	R_9 = 12 kΩ
R_2 = 4 kΩ	R_{10} = 2 kΩ
R_3 = 5 kΩ	R_{11} = 4.5 kΩ
R_5 = 50 Ω	R_{12} = 500 Ω
R_6 = 6 kΩ	R_{13} = 20 kΩ
R_7 = 11.5 kΩ	V_{CC} = 18 V
R_8 = 500 Ω	



Q_1 è un MOS a canale p resistivo con V_T = -1 V; Q_2 è un transistore MOS a canale n resistivo con V_T = 1 V; per entrambi i MOS, la corrente di drain in saturazione è data da $I_D=k(V_{GS}-V_T)^2$ con k = 0.5 mA/V^2.
Con riferimento al circuito in figura:

1) Calcolare il valore della resistenza R_4 in modo che, in condizioni di riposo, la tensione sul drain di Q_2 sia 14 V. Determinare, inoltre, il punto di riposo dei due transistori e verificarne la saturazione. (R_4=11950 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. (V_U/Vi=-2.922)

Esercizio B

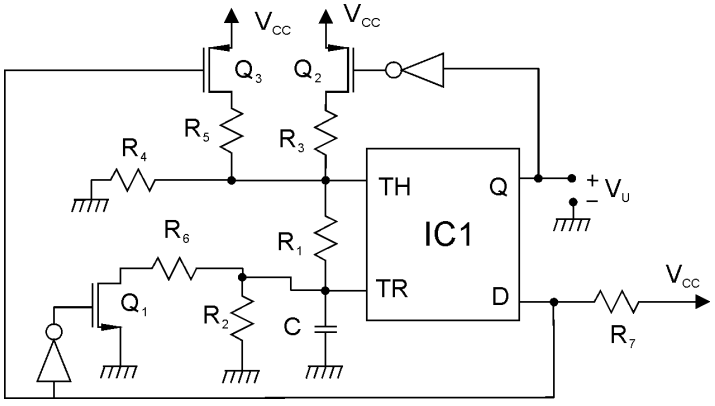
Progettare una porta logica in tecnologia CMOS, utilizzando la tecnica della pull-up network e della pull-down network, che implementi la funzione logica:

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

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 di tutti i transistori.

Esercizio C

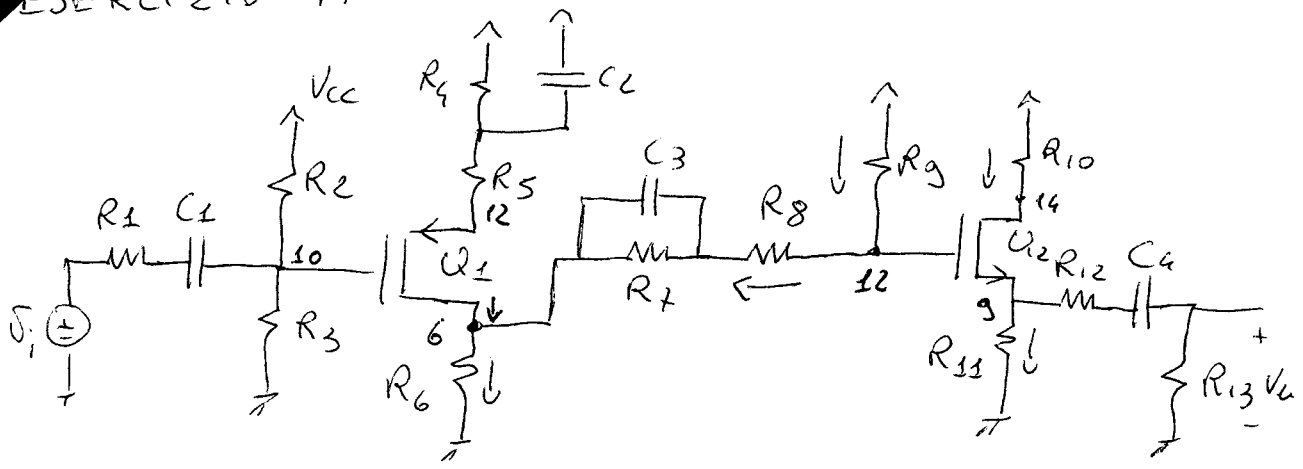
R_1 = 200 Ω	R_6 = 3 kΩ
R_2 = 5 kΩ	R_7 = 1 kΩ
R_3 = 1 kΩ	C = 150 nF
R_4 = 4 kΩ	V_{CC} = 6 V
R_5 = 6 kΩ	



Il circuito IC_1 è un NE555 alimentato a V_{CC} = 6 V; Q_1 ha una R_{on} = 0 e V_T = 1V; Q_2 e Q_3 hanno una R_{on} = 0 e V_T = -1V; gli inverter sono ideali. Determinare la frequenza del segnale di uscita del multivibratore in figura. (f=2189.8 Hz)

APPELLO 06/06/2019

ESERCIZIO A



$R_1 = 200\,\Omega$
$R_2 = 4\,k\Omega$
$R_3 = 5\,k\Omega$
$R_5 = 50\,\Omega$
$R_6 = 6\,k\Omega$
$R_7 = 11.5\,k$
$R_8 = 500\,\Omega$
$R_9 = 12\,k$
$R_{10} = 2\,k$
$R_{11} = 4.5\,k$
$R_{12} = 500$
$R_{13} = 20\,k$
$V_{cc} = 18\,V$
$K = 0.5\ \frac{mA}{V}$

1) Valore di R_4 per $V_{D2} = 14\,V$

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

$$I_{G2} = 0 \Rightarrow I_{S2} = I_{D2} = 2\,mA$$

$$V_{S2} = R_{11} I_{S2} = 9\,V$$

hp: Q_2 SATURO $\Rightarrow I_{D2} = K(V_{GS2} - V_T)^2$

$$V_{GS2} = V_T \pm \sqrt{\frac{I_{D2}}{K}} \overset{\text{MOS}}{=} V_T + \sqrt{\frac{I_{D2}}{K}} = 3\,V$$

$$V_{DS2} = V_{D2} - V_{S2} = 14 - 9 = 5\,V$$

$V_{DS2} > V_{GS2} - V_T$;

$5 > 3 - 1 = 2$ OK VERIFICA

$$g_{m2} = 2k(V_{GS2} - V_T) = 2 \times 10^{-3}\ A/V$$

$$V_{G2} = V_{GS2} + V_{S2} = 3 + 9 = 12\,V$$

$$I_9 = \frac{V_{cc} - V_{G2}}{R_9} = \frac{18 - 12}{12 \times 10^3} = 0.5\,mA$$

$I_G = 0 \Rightarrow I_8 = I_9$

$$V_{D1} = V_{G2} - (R_7 + R_8) I_9 = 6\,V$$

$$I_6 = \frac{V_{D1}}{R_6} = 1\,mA$$

$$I_{D1} = I_6 - I_{7,8,9} = 0.5\,mA$$

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

Q_2: $I_{D2} = 2\,mA$, $V_{DS2} = 5\,V$, $V_{GS2} = 3\,V$, $g_{m2} = 2 \times 10^{-3}\ A/V$

$$V_{G1} = V_{CC}\frac{R_3}{R_2+R_3} = 10V$$

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

$$V_{GS_1} = V_{T1} \pm \sqrt{\frac{I_{D1}}{K}} \overset{PROS}{=} V_{T1} - \sqrt{\frac{I_{D1}}{K}} = -1 - 1 = -2V$$

$$V_{S_1} = V_{G1} - V_{GS_1} = 10 - (-2) = 12V$$

$$V_{DS_1} = V_{D1} - V_{S1} = 6 - 12 = -6V$$

$$V_{DS1} \leq V_{GS1} - V_{T1} \; ?$$

$$-6 \leq -2 - (-1) = -1 \quad \text{OK VERIFICA}$$

$$g_{m1} = 2K|V_{GS1} - V_{T1}| = 2K|-2-(-1)| = 10^{-3}\ A/V$$

Q_1: $I_{D_1} = 0.5\ mA$, $V_{DS1} = -6V$, $V_{GS1} = -2V$, $g_{m1} = 10^{-3}\ A/V$

$$V_{S1} = V_{CC} - (R_4 + R_5) I_{D1}$$

$$(R_4 + R_5) = \frac{V_{CC} - V_{S1}}{I_{D1}} = \frac{18-12}{0.5\times10^{-3}} = 12000\ \Omega$$

$$R_4 = 12\times10^3 - R_5 = 12\times10^3 - 50 = 11950\ \Omega$$

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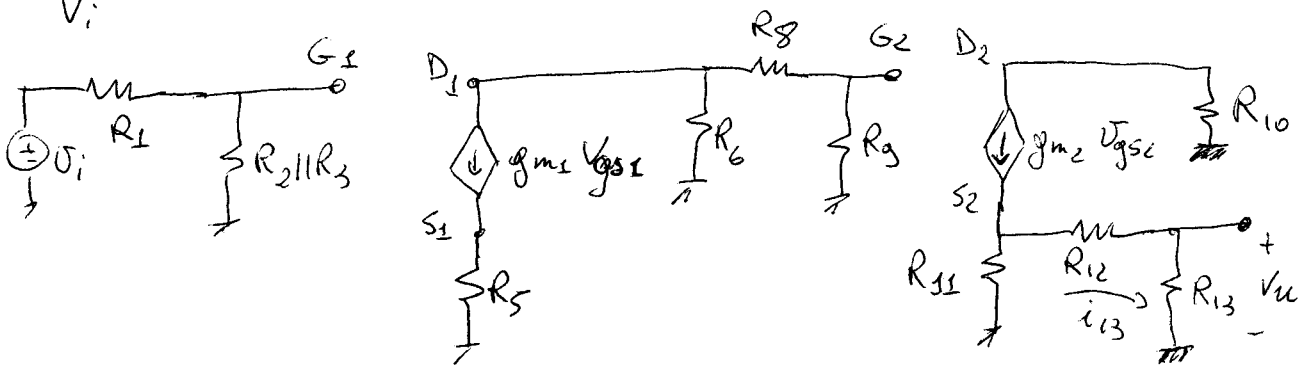
2) $\frac{V_u}{V_i}$ per C_1, C_2, C_3, C_4 CORTOCIRCUITI



$$V_u = R_{13}\, i_{13}$$

$$i_{13} = (g_{m2} v_{gs2})\frac{R_{11}}{R_{11}+R_{12}+R_{13}}$$

$$v_{s2} = (g_{m2} v_{gs2})[R_{11} \| (R_{12}+R_{13})]$$

$$v_{gs2} = v_{g2} - v_{s2} = v_{g2} - g_{m2} v_{gs_2}[R_{11}\|(R_{12}+R_{13})]$$

$$v_{gs2} = \frac{v_{g2}}{1 + g_{m2}[R_{11} \| (R_{12}+R_{13})]}$$

$$v_{g2} = (-g_{m1} v_{gs1}) \frac{R_6}{R_6 + R_8 + R_9} R_9$$

$$v_{s1} = (g_{m1} v_{gs1}) R_5$$

$$v_{gs1} = v_{g1} - g_{m1} v_{gs1} R_5$$

$$\Rightarrow v_{gs1} = \frac{v_{g1}}{1 + g_{m1} R_5}$$

$$v_{g1} = v_i \frac{R_2 \| R_3}{R_1 + R_2 \| R_3}$$

$$\frac{v_u}{v_i} = R_{13}\, g_{m2}\, \frac{R_{11}}{R_{11}+R_{12}+R_{13}}\, \frac{1}{1+g_{m2}[R_{11} \| (R_{12}+R_{13})]}\, (-g_{m1})\, \frac{R_6 R_9}{R_6+R_8+R_9}$$

(20×10^3, 2×10^{-3}, 0.18, $1/8.38 = 0.11933$, 10^{-3}, 3891.892)

$$\frac{1}{1+g_{m1}R_5} \cdot \frac{R_2 \| R_3}{R_1 + R_2 \| R_3} = -2.922 \quad (9.31\ \text{dB})$$

($1/1.05 = 0.3524$, 0.9174)

ESERCIZIO B

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

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

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

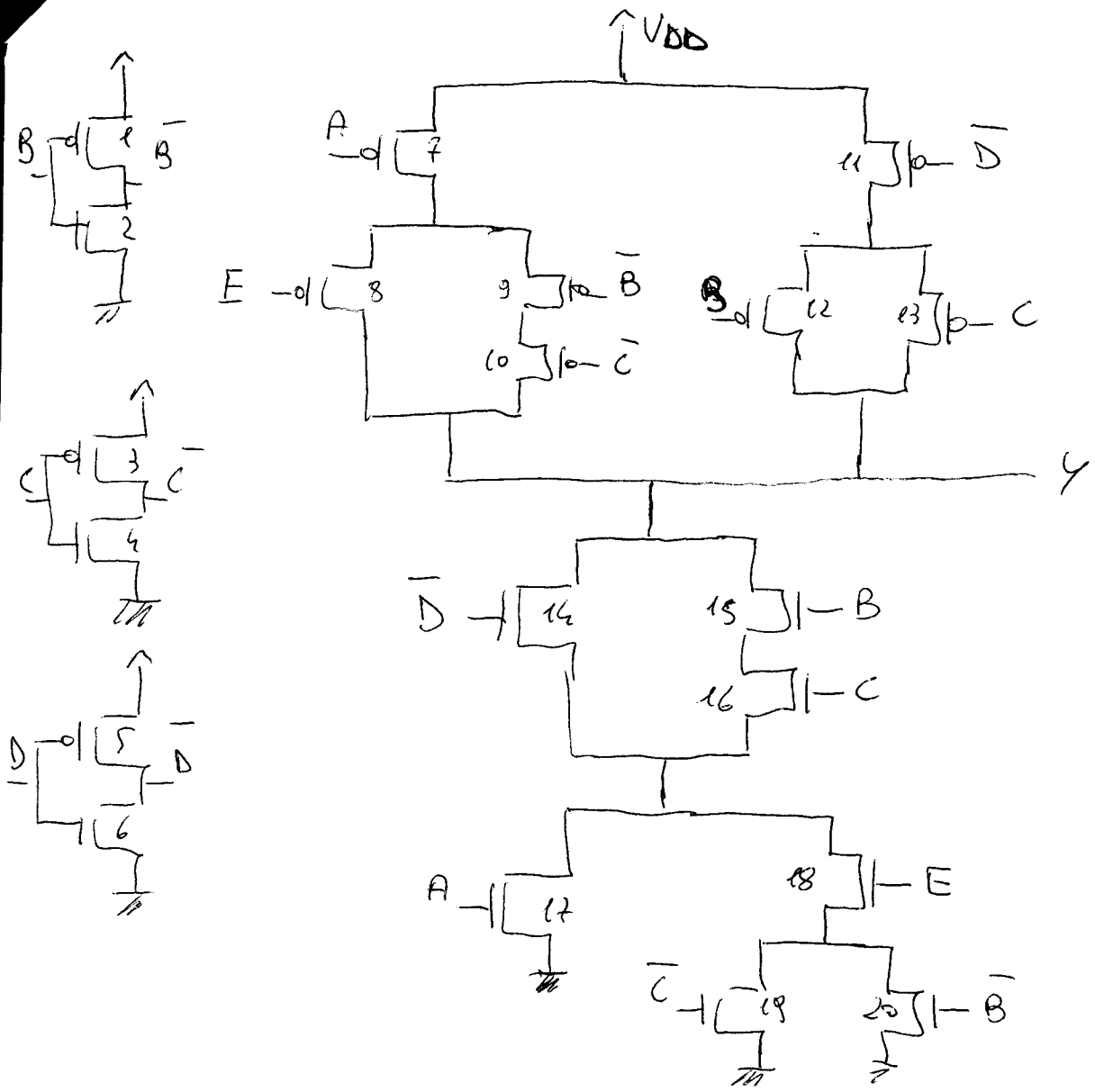
$$= \bar{A}\bar{E}(D+\bar{D}) + \bar{B}D(\bar{E}+E) + \bar{C}D(\bar{E}+E) + \bar{A}BC =$$

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

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

$$\#\,\text{NOS} = 7\times2 + 3\times2 = 20$$

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



INVERTER

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

PUN

·) SERIE $Q_7 - Q_9 - Q_{10}$: $\left(\frac{W}{L}\right)_{7,9,10} = x = 15$

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

·) SERIE $Q_7 - Q_8$ con Q_7 GIÀ DIMENSIONATO : $\left(\frac{W}{L}\right)_8 = y = 7.5$

$\frac{1}{y} + \frac{1}{15} = \frac{1}{p} \Rightarrow \frac{1}{y} = \frac{1}{5} - \frac{1}{15} = \frac{2}{15} \Rightarrow y = 7.5$

·) SERIE $Q_{11} - Q_{13}$ oppure $Q_{11} - Q_{12}$: $\left(\frac{W}{L}\right)_{11,12,13} = z = 10$

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

PDN

·) $Q_{15} - Q_{16} - Q_{18} - Q_{13}$ NON È POSSIBILE per C o $\bar{C}$

·) $Q_{15} - Q_{16} - Q_{18} - Q_{20}$ = = = = B e $\bar{B}$

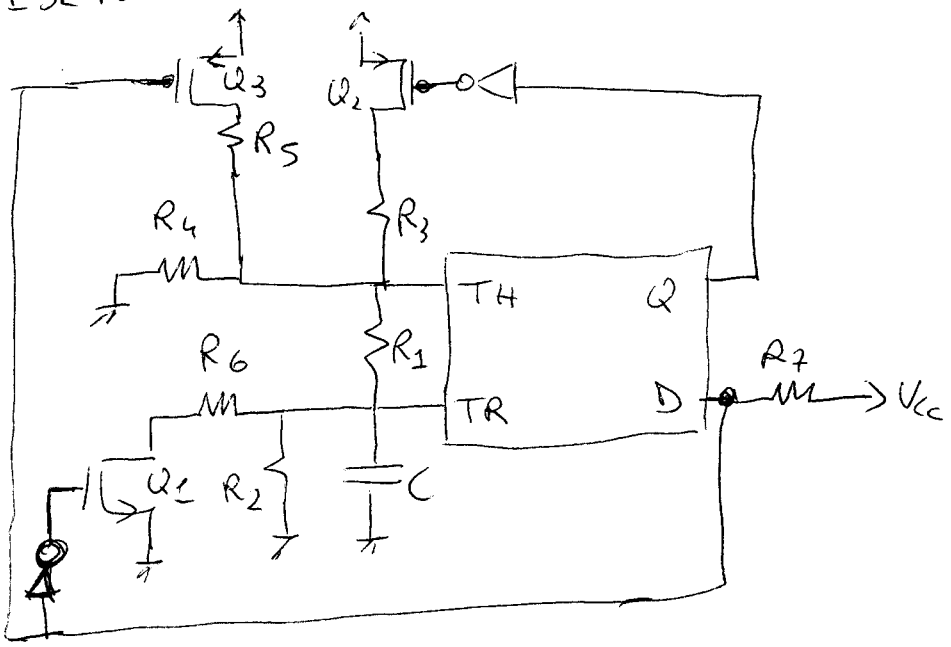
·) SERIE $Q_{14} - Q_{18} - Q_{19}$

$Q_{14} - Q_{13} - Q_{20}$ $\left(\frac{W}{L}\right)_{14,15,16,17,18,13,20} = K = 6$

$Q_{15} - Q_{16} - Q_{17}$

$\frac{1}{K} + \frac{1}{K} + \frac{1}{K} = \frac{1}{n} \Rightarrow K = 3n = 6$

ESERCIZIO C



$R_1 = 200\,\Omega$

$R_2 = 5\,K\Omega$

$R_3 = 1\,K\Omega$

$R_4 = 4\,K\Omega$

$R_5 = 6\,K\Omega$

$R_6 = 3\,K\Omega$

$R_7 = 1\,K\Omega$

$C = 150\,nF$

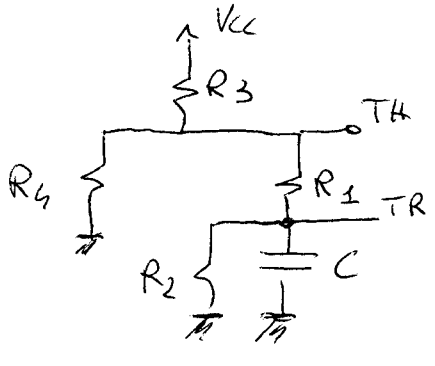
$V_{CC} = 6\,V$

1ª FASE : $Q = 1$; D : HI

$V_{g1} = 0\,V$; $V_{d1} = 0\,V \Rightarrow V_{gd1} = 0\,V < V_T = 1V \Rightarrow$ Q_1 OFF

$V_{g2} = 0\,V$; $V_{d2} = 6V \Rightarrow V_{gd2} = -6V < V_T = -1V \Rightarrow$ Q_2 ON

$V_{g3} = 6V$; $V_{d3} = 6V \Rightarrow V_{gs3} = 0\,V > V_T = -1V \Rightarrow$ Q_3 OFF

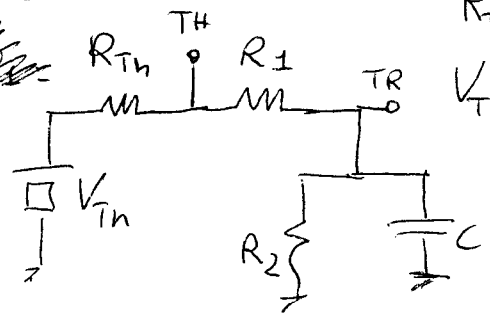


$\Rightarrow$

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

$R_{Th} = R_3 \| R_4 = 800\,\Omega$

$V_{Th} = V_{CC} \frac{R_4}{R_3 + R_4} = 4.8\,V$



$V_1 = V_{Th} \dfrac{1}{R_{Th} + R_1 + R_2} \cdot R_2 = 4V$

Se $V_{TH} = \frac{2}{3} V_{CC} = 4V \Rightarrow I_1 = \dfrac{V_{Th} - V_{TH}}{R_{Th}} = 1\,mA$

$V_{com1} < V_{TH} - R_1 I_1 = 3.8V$

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

$2V < 3.8V < 4V$ OK

$R_{VC_1} = R_2 \,||\, (R_1 + R_{Th}) = 833.\overline{3}\ \Omega$

$\tau_1 = C R_{VC1} = 125\,\mu s$

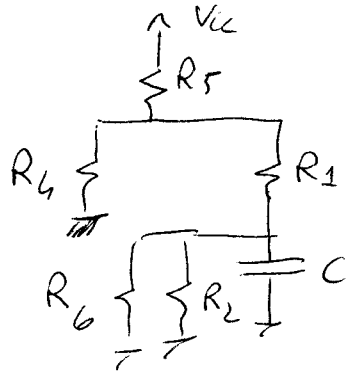
$T_1 = \tau_1 \ln\left(\dfrac{V_{i1} - V_{f1}}{V_{com1} - V_{f1}}\right) = 2.878 \times 10^{-4}\ s$

2ª fase: $Q = \phi$; $D = \phi$

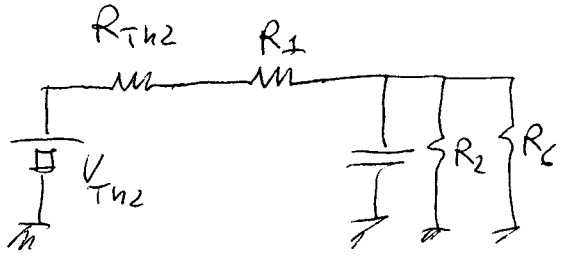
$V_{g1} = 6V \quad V_{S1} = \phi V \Rightarrow V_{gs1} = 6V > V_T = 1V \Rightarrow Q_1$ ON

$V_{g2} = 6V \quad V_{S2} = 6V \Rightarrow V_{gs2} = \phi V > V_T = -1V \Rightarrow Q_2$ OFF

$V_{g3} = \phi V \quad V_{S3} = 6V \Rightarrow V_{gs3} = -6V < V_T = -1V \Rightarrow Q_3$ ON



$\Rightarrow$



$R_{Th2} = R_4 \,||\, R_5 = 2400\ \Omega$

$V_{Th2} = V_{CC} \dfrac{R_4}{R_4 + R_5} = 2.4V$

$V_{f2} = V_{Th2} \dfrac{1}{R_{Th2} + R_1 + R_2 \,||\, R_6} (R_2 \,||\, R_6) = 1.006V$

$V_{i2} = V_{com1} = 3.8V$

$V_{com2} = V_{i1} = 2V$

$V_{i2} > V_{com2} > V_{f2}$

$3.8V > 2V > 1.006V$ OK

$R_{VC2} = R_2 \,||\, R_6 \,||\, (R_1 + R_{Th2}) = 1089.385\ \Omega$

$\tau_2 = C R_{VC2} = 1.634 \times 10^{-4}\ s$

$T_2 = \tau_2 \ln\left(\dfrac{V_{i2} - V_{f2}}{V_{com2} - V_{f2}}\right) = 1.6888 \times 10^{-4}\ s$

$T = T_1 + T_2 = 4.567 \times 10^{-4}\ s$

$f = \dfrac{1}{T} = 2189.8\ Hz$