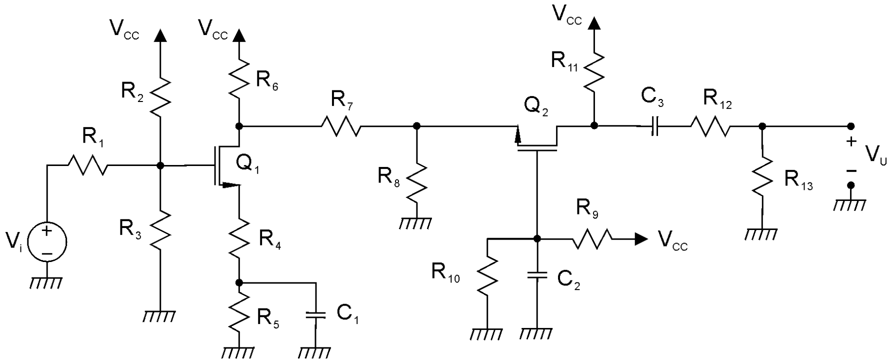
ELETTRONICA DIGITALE
Corso di Laurea in Ingegneria Informatica

Prova scritta del 31 gennaio 2019

Esercizio A

R_1 = 20 kΩ	R_9 = 10 kΩ
R_2 = 20 kΩ	R_{10} = 20 kΩ
R_3 = 20 kΩ	R_{11} = 5 kΩ
R_4 = 50 Ω	R_{12} = 200 Ω
R_5 = 1450 Ω	R_{13} = 20 kΩ
R_6 = 8 kΩ	V_{CC} = 18 V
R_8 = 96 kΩ	



Q_1 e Q_2 sono transistori MOS a canale n resistivi con V_T = 1 V e la corrente di drain in saturazione 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_7 in modo che, in condizioni di riposo, la tensione sul drain di Q_2 sia 13.1 V. Determinare, inoltre, il punto di riposo dei due transistori e verificarne la saturazione. (R: R_7 = 636.4 Ω)
2) Determinare l'espressione e il valore di V_U/Vi alle frequenze per le quali C_1, C_2 e C_3 possono essere considerati dei corto circuiti. (R: V_U/Vi = - 2)

Esercizio B

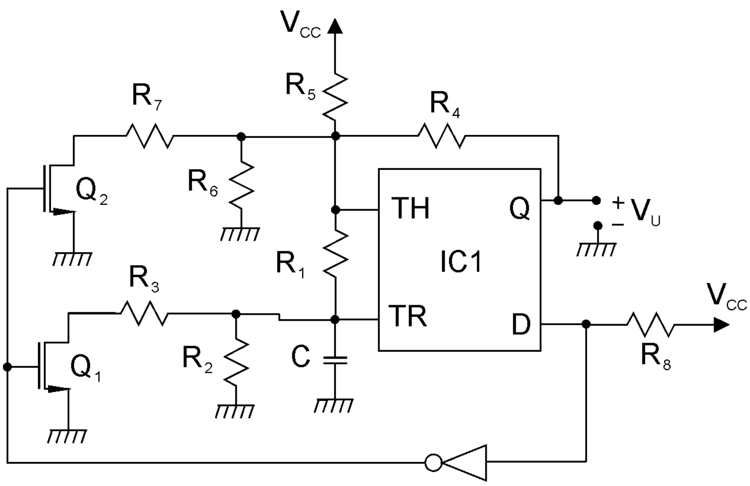
Progettare una porta logica in tecnologia CMOS, utilizzando la tecnica della pull-up network e della pull-down network, che implementi la funzione logica:

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

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 dei transistori. (R: N = 20)

Esercizio C

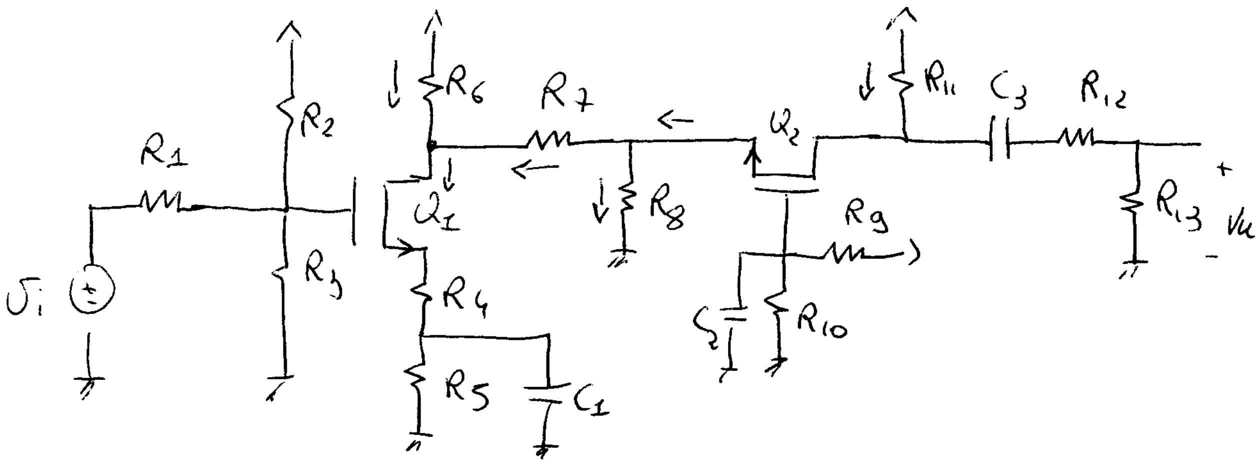
R_1 = 100 Ω	R_6 = 6 kΩ
R_2 = 1900 Ω	R_7 = 400 Ω
R_3 = 1900 Ω	R_8 = 1 kΩ
R_4 = 800 Ω	C = 680 nF
R_5 = 800 Ω	V_{CC} = 6 V



Il circuito IC_1 è un NE555 alimentato a V_{CC} = 6 V; Q_1 e Q_2 hanno una R_{on} = 0 e V_T = 1V; l'inverter è ideale. Determinare la frequenza del segnale di uscita del multivibratore in figura. (R: f = 2443 Hz)

APPELLO 31/01/2019

ESERCIZIO A



$R_1 = 20K\Omega$
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$R_5 = 1450\Omega$
$R_6 = 8K\Omega$
$R_8 = 96K\Omega$
$R_9 = 10K\Omega$
$R_{10} = 20K\Omega$
$R_{11} = 5K\Omega$
$R_{12} = 200\Omega$
$R_{13} = 20K\Omega$

1) Det R_7 per $V_{D2} = 13.1V$

$I_{D2} = I_{11} = \dfrac{V_{DD} - V_{D2}}{R_{11}} = 980\ \mu A$; $I_{G2} = \phi$

hp Q_2 saturo $\Rightarrow V_{GS_2} = V_{T2} + \sqrt{\dfrac{I_{D2}}{K}} = 2.4V$

$V_{G2} = V_{CC}\dfrac{R_{10}}{R_9 + R_{10}} = 12\,V$

$V_{S2} = V_{G2} - V_{GS_2} = 9.6\,V$

$V_{DS_2} = V_{D2} - V_{S2} = 13.1V - 9.6 = 3.5V > V_{GS_2} - V_{T2} = 1.4V \Rightarrow$ verifica OK

$g_{m2} = 2K(V_{GS2} - V_{T2}) = 1.4 \times 10^{-3}\ A/V$

$Q_2: \begin{cases} I_{D2} = 980\mu A \\ V_{DS2} = 3.5V \\ V_{GS2} = 2.4V \\ g_{m2} = 1.4 \times 10^{-3}\ A/V \end{cases}$

$I_8 = \dfrac{V_{S2}}{R_8} = 100\,\mu A$

$I_7 = I_{D2} - I_8 = 880\,\mu A$ $\quad I_{G1} = \phi$

$V_{G1} = V_{CC}\dfrac{R_1 \| R_3}{(R_1 \| R_3) + R_2} = 6\,V$

hp Q_1 saturo $\Rightarrow I_{DS} = K(V_{GS1} - V_T)^2$

$I_{DS_1} = K[V_{G1} - V_{S1} - V_T]^2 = K[6 - (R_4 + R_5)I_{DS1} - 1]^2 =$

$= K[5 - 1500\,I_{DS1}]^2 = K(25 + 225 \times 10^4\, I_{DS1}^2 - 15000\, I_{DS1}) =$

$= 0.0125 + 1125\, I_{DS1}^2 - 7.5\, I_{DS1}$

$$1125\, I_{DS1}^2 - 8.5\, I_{DS} + 0.0125 = \phi$$

$$I_{DS} = \frac{8.5 \pm \sqrt{72.25 - 56.25}}{2250} = \frac{8.5 \pm 4}{2250} \begin{cases} I_{DSa} = 5.\bar{5}\ mA \\ I_{DSb} = 2\ mA \end{cases}$$

Per $I_{DSa} = 5.5\ mA$ si ha $V_{S_1} = 8.\bar{3}\ V \Rightarrow V_{GS1} = -2.\bar{3}\ V < V_T$ NON ACCETTABILE

$I_{DS2} = 2\ mA \Rightarrow V_{S1} = 3V \Rightarrow V_{GS1} = 6 - 3 = 3V > V_T$ ACCETTABILE

$I_6 = I_{DS1} - I_7 = 1.12\ mA$

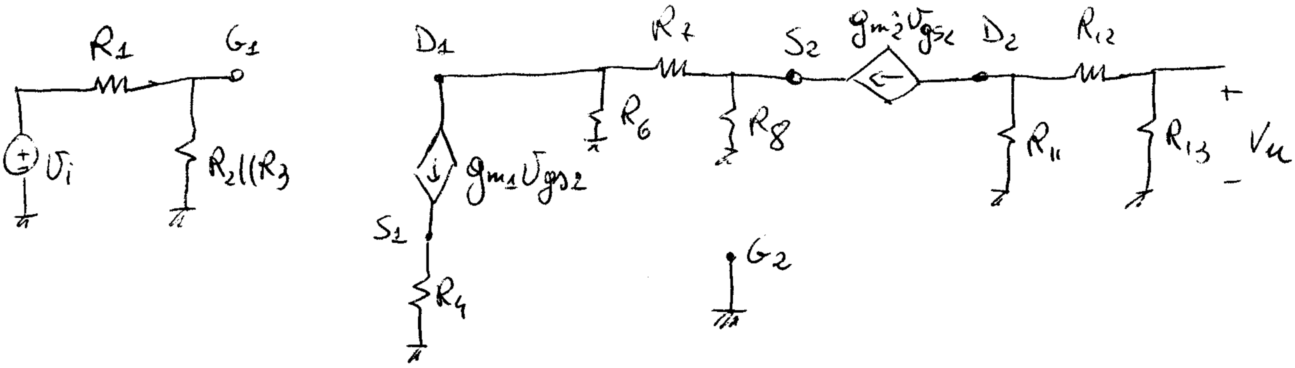
$V_{D1} = V_{CC} - R_6 I_6 = 9.04\ V$

$V_{DS1} = V_{D1} - V_{S1} = 9.04 - 3V = 6.04\ V > V_{GS1} - V_T = 2V \Rightarrow$ hp ~~satur~~ OK

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

$$Q_1 : \begin{cases} I_{D1} = 2mA \\ V_{DS1} = 6.04V \\ V_{GS1} = 3V \\ g_{m1} = 2 \times 10^{-3}\ A/V \end{cases}$$

$$R_7 = \frac{V_{S2} - V_{D1}}{I_7} = \frac{9.6 - 9.04}{880 \times 10^{-6}} = 636.\overline{36}\ \Omega$$



$$\left.\begin{aligned} V_u &= (-g_{m2} v_{gs2}) \frac{R_{11}}{R_{11} + R_{12} + R_{13}} \cdot R_{13} \\ v_{g2} &= \phi \end{aligned}\right\} \Rightarrow V_u = g_{m2} v_{s2} \frac{R_{11} R_{13}}{R_{11} + R_{12} + R_{13}}$$

$$v_{s2} = (-g_{m1} v_{gs1}) \frac{R_6}{R_6 + R_7 + \left(R_8 \| \frac{1}{g_{m2}}\right)} \left(R_8 \| \frac{1}{g_{m2}}\right)$$

$$v_{s1} = (g_{m1} v_{gs1}) R_4$$

$$v_{gs_1} = v_{g_1} - (g_{m_1} v_{gs_1}) R_4$$

$$v_{gs_1} = \frac{v_{g_1}}{1 + g_{m_1} R_4}$$

$$v_{g_1} = v_i \frac{R_2 \| R_3}{(R_2 \| R_3) + R_1}$$

$$\frac{V_u}{V_i} = g_{m_2} \frac{R_{11} R_{13}}{R_{11} + R_{12} + R_{13}} (-g_{m_1}) \frac{R_6}{R_6 + R_7 + (R_8 \| \frac{1}{g_{m_2}})} (R_8 \| \frac{1}{g_{m_2}}) \frac{1}{1 + g_{m_1} R_4} \frac{R_2 \| R_3}{R_1 + R_2 \| R_3} =$$

(1.4×10^{-3}) 3968.25 2×10^{-3} 0.856 709.01 $0.\overline{90}$ $0.\overline{3}$

$$= -2.0436 \qquad \left| \frac{V_u}{V_i} \right| = 6.2078 \text{ dB}$$

ESERCIZIO B

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

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

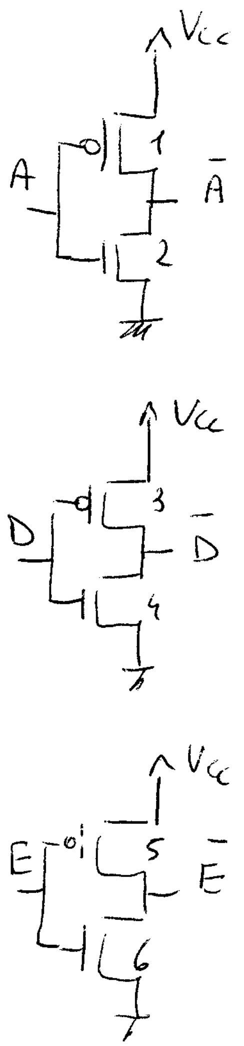
$$= \bar{A}\underset{o}{\bar{C}}D + \bar{A}\underset{\times}{\bar{B}}D + \bar{A}\underset{o}{\bar{C}}\bar{D} + \bar{A}\bar{E} + A\underset{\times}{\bar{B}}D + A\bar{B}E =$$

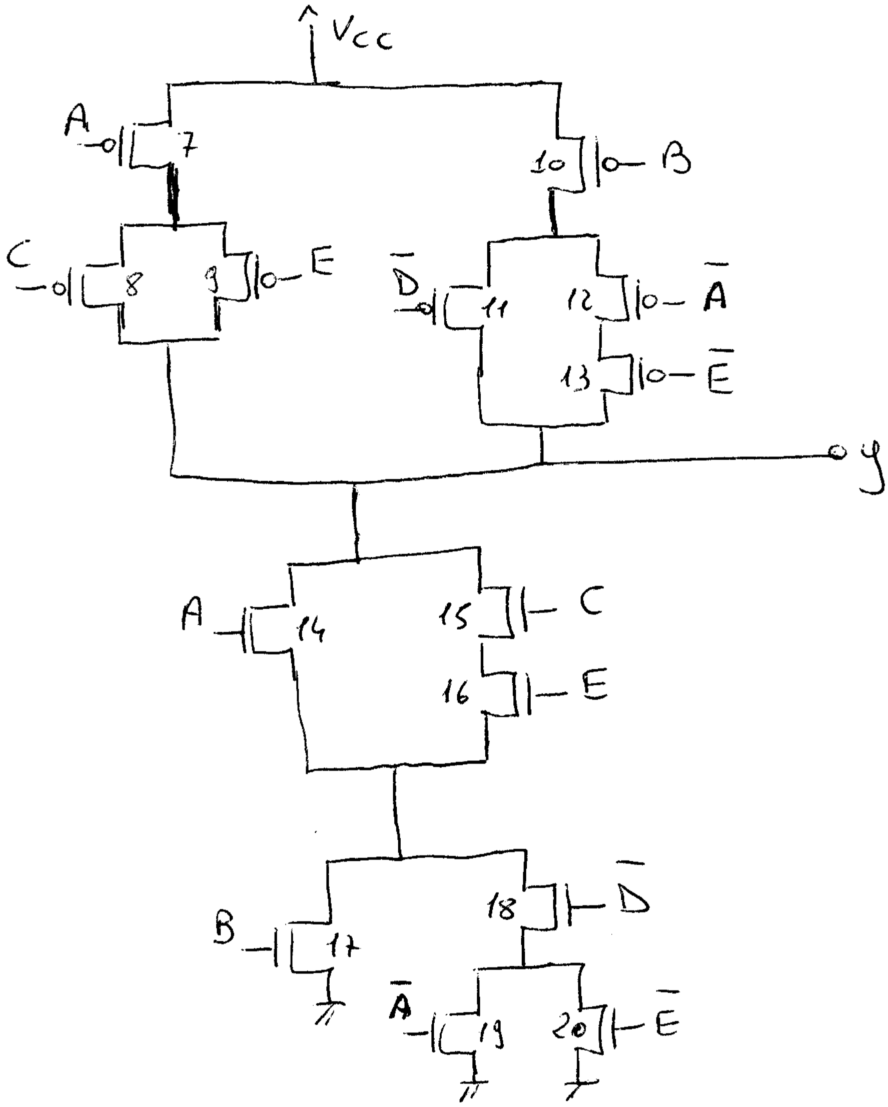
$$= \bar{A}\bar{C}(D+\bar{D}) + \bar{B}D(\bar{A}+A) + \bar{A}\bar{E} + A\bar{B}E =$$

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

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

$\#$ MOS $= 7\times 2 + 3\times 2 = 20$





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

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

} INVERTER DI BASE

5

ëx

PULL - UP

-) $Q_{10} - Q_{12} - Q_{13}$

$$\frac{1}{x} + \frac{1}{x} + \frac{1}{x} = \frac{1}{p} \Rightarrow x = 3p = 15 \Rightarrow \left(\frac{W}{L}\right)_{10,12,13} = 15$$

-) $Q_{10} - Q_{11}$

$$\frac{1}{y} + \frac{1}{3p} = \frac{1}{p} \Rightarrow \frac{1}{y} = \frac{2}{3p} \Rightarrow y = \frac{3}{2}p = 7.5 \Rightarrow \left(\frac{W}{L}\right)_{11} = 7.5$$

·) $Q_7 - Q_8$; $Q_7 - Q_9$

$$\frac{1}{z} + \frac{1}{z} = \frac{1}{p} \Rightarrow z = 2p = 10 \Rightarrow \left(\frac{W}{L}\right)_{7,8,9} = 10$$

PULL - DOWN

-) $Q_{15} - Q_{16} - Q_{18} - Q_{20}$ NON È POSSIBILE perché F e $\bar{E}$

·) $Q_{15} - Q_{16} - Q_{18} - Q_{19}$

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

·) $Q_{15} - Q_{16} - Q_{17}$

$$\frac{1}{x} + \frac{2}{4n} = \frac{1}{n} \Rightarrow \frac{1}{x} = \frac{1}{2n} \Rightarrow x = 2n = 4 \quad \left(\frac{W}{L}\right)_{17} = 4$$

·) $Q_{14} - Q_{18} - Q_{19}$; $Q_{14} - Q_{18} - Q_{20}$

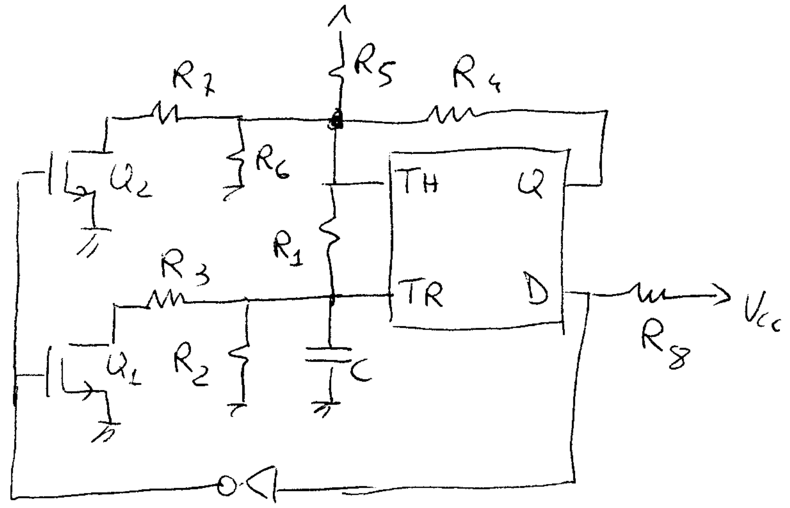
NON POSSIBILE

·) $Q_{14} - Q_{18} - Q_{20}$

$$\frac{1}{y} + \frac{1}{4n} + \frac{1}{y} = \frac{1}{n} \Rightarrow \frac{2}{y} = \frac{3}{4n} \Rightarrow y = \frac{8}{3}$$

$$\left(\frac{W}{L}\right)_{14,20} = \frac{8}{3}n = \frac{16}{3}$$

SERCIZIO C



$R_1 = 100\,\Omega$

$R_2 = 1900\,\Omega$

$R_3 = 1900\,\Omega$

$R_4 = 800\,\Omega$

$R_5 = 800\,\Omega$

$R_6 = 6\,k\Omega$

$R_7 = 400\,\Omega$

$R_8 = 1\,k\Omega$

$C = 680\,nF$

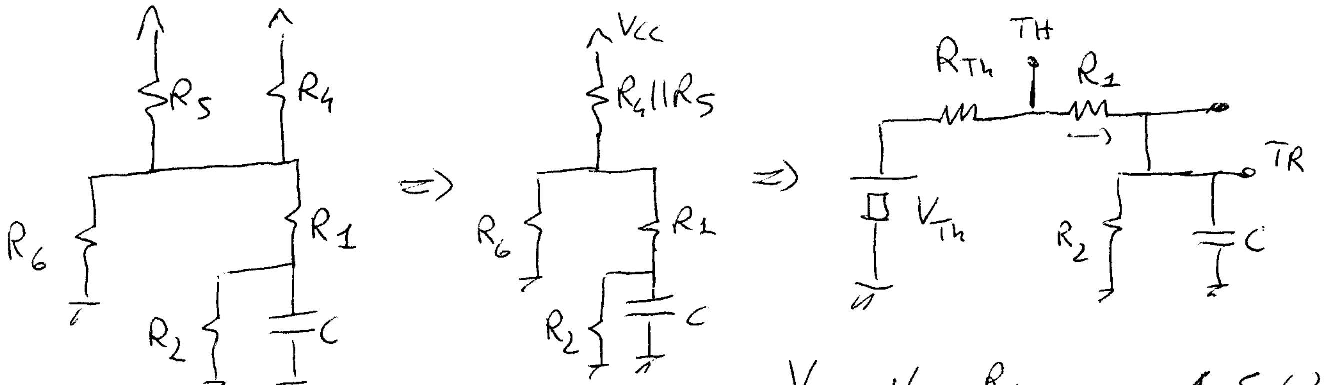
$V_{cc} = 6\,V$

1° CASO

$Q = 1$

$D = HI \Rightarrow V_{G1} = \phi\,V \quad V_{S1} = \phi V \Rightarrow V_{GS1} = \phi V < V_T$ Q_1 OFF

$V_{G2} = \phi V \quad V_{S2} = \phi V \Rightarrow V_{GS2} = \phi V < V_T$ Q_2 OFF



$V_{Th} = V_{cc} \dfrac{R_6}{R_6 + R_4 \| R_5} = 5.625\,V$

$R_{Th} = R_4 \| R_5 \| R_6 = 375\,\Omega$

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

$V_{f1} = V_{Th} \dfrac{1}{R_{Th} + R_1 + R_2} \cdot R_2 = 4.5\,V$

So $V_{TH} = 4\,V \Rightarrow I_1 = \dfrac{V_{Th} - V_{TH}}{R_{Th}} = 4.\bar{3}\,mA$

$V_{COR1} = V_{TH} - R_1 I_1 = 3.5\bar{6}\,V$

$V_{i1} < V_{COR1} < V_{f1}$

$2 < 3.5\bar{6} < 4.5$ OK

$R_{V1} = R_2 \| (R_1 + R_{Th}) = 380\,\Omega$

$\tau_1 = 258.4\,\mu s$

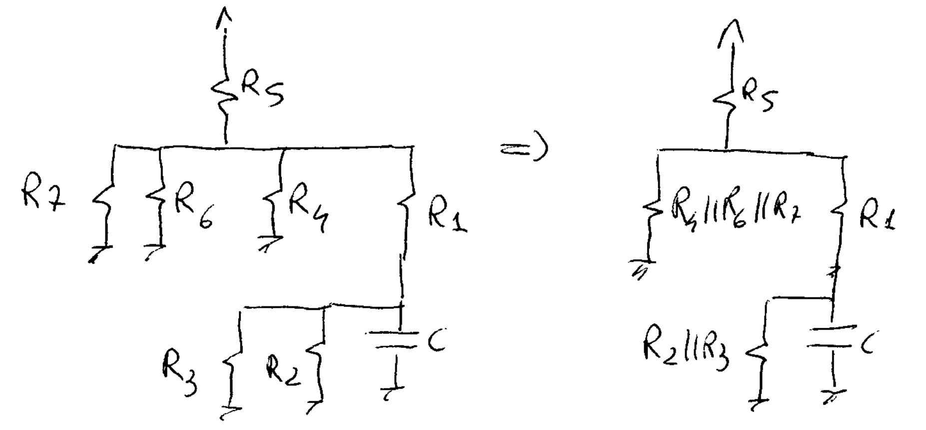
$T_1 = \tau_1 \ln\left(\dfrac{V_{i1} - V_{f1}}{V_{COR1} - V_{f1}}\right) = 254.597\,\mu s$

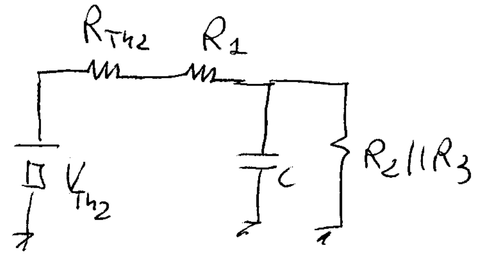
2° CASO

$Q = \phi$

$D = \phi \Rightarrow V_{G1} = 6V \quad V_{S1} = \phi \quad V_{GS1} = 6V > V_T \Rightarrow Q_1$ ON

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





$$V_{Th2} = V_{CC} \frac{(R_4 || R_6 || R_7)}{(R_4 || R_6 || R_7) + R_5} = 1.4516 V$$

$$R_{Th2} = R_4 || R_6 || R_7 || R_5 = 193.548 k$$

$V_{i2} = V_{COR1} = 3.5\bar{6}\ V$

$V_{COR2} = V_{i1} = 2V$

$$V_{f2} = V_{Th2} \frac{1}{R_{Th2} + R_1 + R_2 || R_3} \cdot (R_2 || R_3) = 1.1089 V$$

$V_{i2} > V_{COR2} > V_{f2}$

$3.5\bar{6}V > 2V > 1.1089V$ OK

$R_{V2} = R_2 || R_3 || (R_1 + R_{Th2}) = 224.25\ \Omega$

$\tau_2 = C R_{V2} = 152.493\ \mu s$

$$T_2 = \tau_2 \ln \left(\frac{V_{i2} - V_{f2}}{V_{COR2} - V_{f2}} \right) = 154.712\ \mu s$$

$T = T_1 + T_2 = 409.309\ \mu s$

$f = \frac{1}{T} = 2443.14\ Hz$