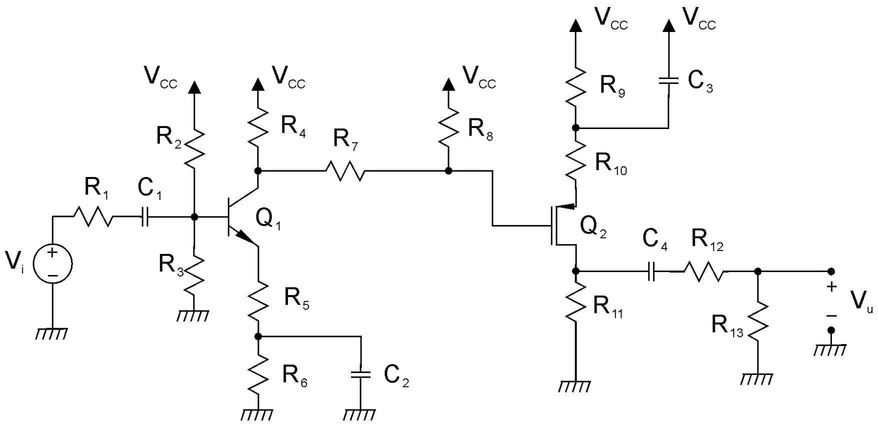
ELETTRONICA DIGITALE

Corso di Laurea in Ingegneria Informatica

Prova scritta del 28 giugno 2018

Esercizio A

R_1 = 1 kΩ	R_9 = 2.5 kΩ
R_2 = 286 kΩ	R_{10} =500 Ω
R_4 = 6250 Ω	R_{11} = 3.5 kΩ
R_5 = 200 Ω	R_{12} = 1 kΩ
R_6 = 1300 Ω	R_{13} = 9 kΩ
R_7 = 2500 Ω	V_{CC} = 18 V
R_8 = 22.5 kΩ	



Q_1 è un transistore BJT BC109B resistivo con $h_{re} = h_{oe} = 0$. Q_2 è un transistore MOS a canale p resistivo, 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_3 in modo che, in condizioni di riposo, la tensione sul drain di Q_2 sia 7 V. Determinare, inoltre, il punto di riposo dei due transistori e verificare la saturazione di Q_2. (R: R_3 = 85840 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 = 47)

Esercizio B

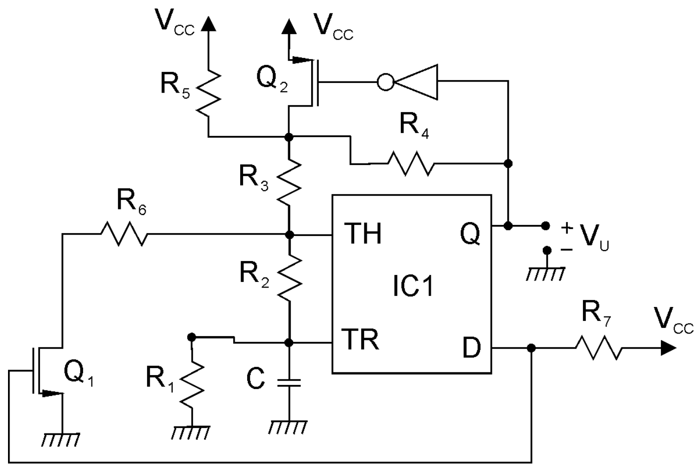
Progettare una porta logica in tecnologia CMOS, utilizzando la tecnica della pull-up network e della pull-down network, che implementi la funzione logica:

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

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 = 22)

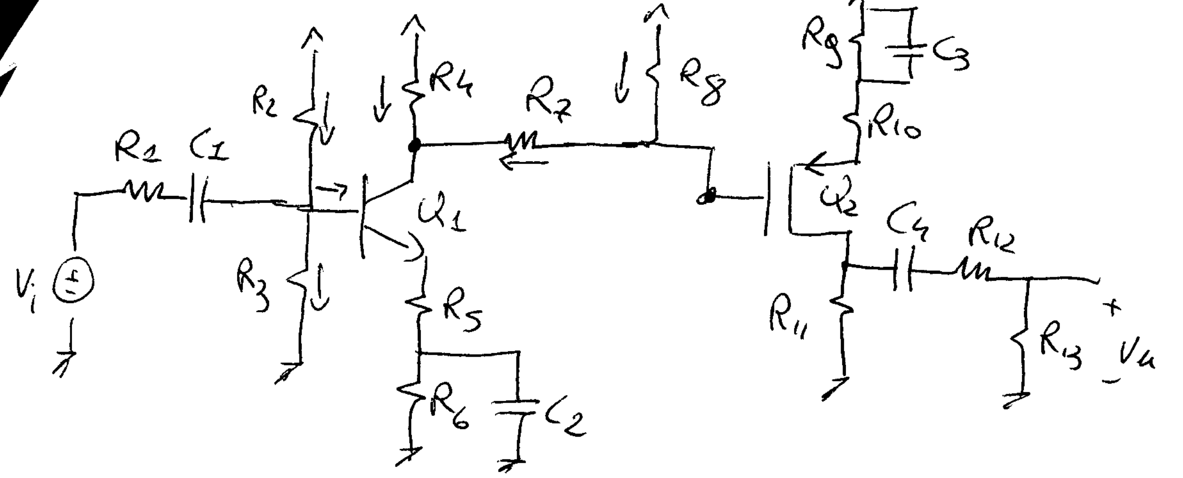
Esercizio C

R_1 = 1.8 kΩ	R_6 = 800 Ω
R_2 = 40 Ω	R_7 = 1 kΩ
R_3 = 200 Ω	C = 47 nF
R_4 = 1920 Ω	**V_{CC} = 6 V**
R_5 = 1920 Ω	



Il circuito IC_1 è un NE555 alimentato a **V_{CC} = 6V**, Q_1 ha una R_{on} = 0 e V_T = 1V, Q_2 ha 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= 11041 Hz)

APPELLO 28/06/2018



$R_1 = 1\,k\Omega$
$R_2 = 286\,k\Omega$
$R_4 = 6250\,\Omega$
$R_5 = 200\,\Omega$
$R_6 = 1300\,\Omega$
$R_7 = 2500\,\Omega$
$R_8 = 22.5\,k\Omega$
$R_9 = 2.5\,k\Omega$
$R_{10} = 500\,\Omega$
$R_{11} = 3.5\,k\Omega$
$R_{12} = 1\,k\Omega$
$R_{13} = 9\,k\Omega$
$V_{CC} = 18\,V$
$K = 0.5\ mA/V^2$
$V_T = -1\,V$

1) R_3 per $V_{D2} = 7V$

$I_{11} = \dfrac{V_D}{R_{11}} = 2\,mA = I_D$

$I_G = \phi \Rightarrow I_D = I_S$

$V_S = V_{CC} - (R_9 + R_{10}) I_D = 12V$

$V_{DS} = V_D - V_S = -5V$

hp Q_2 SATURO $\Rightarrow I_D = K(V_{GS} - V_T)^2$

$V_{GS} = \underset{\text{PMOS}}{V_T} - \sqrt{\dfrac{I_D}{K}} = -1 - 2 = -3V$

$V_{DS} < V_{GS} - V_T$

$-5 < (-3+1) = -2$ $\underline{\underline{OK}}$ hp di SATUR.

$g_m = 2K|V_{GS} - V_T| = 2K|-3+1| = 2 \times 10^{-3}\ \dfrac{A}{V}$

$Q_2 : \begin{cases} V_{DS} = -5V \\ V_{GS} = -3V \\ I_D = 2mA \\ g_m = 2\times 10^{-3}\ \dfrac{A}{V} \end{cases}$

$V_G = V_{GS} + V_S = -3 + 12 = 9V$

$I_8 = \dfrac{V_{CC} - V_G}{R_8} = 0.4\,mA = I_7$

$V_C = V_G - R_7 I_8 = 8V$

$I_4 = \dfrac{V_{CC} - V_C}{R_4} = 1.6\,mA$

$I_C = I_4 + I_7 = 2\,mA$

: $I_B << I_C \Rightarrow I_E \simeq I_C$

$V_E = (R_5 + R_6) I_E = 3V$

$V_{CE} = V_C - V_E = 8 - 3 = 5V$

Per $I_C = 2mA$ e $V_{CE} = 5V$ si ha: $h_{FE} = 290$, $h_{fe} = 300$; $h_{ie} = 4800\Omega$

$I_B = \frac{I_C}{h_{FE}} = 6.896\mu A << I_C \Rightarrow h_P$ ok

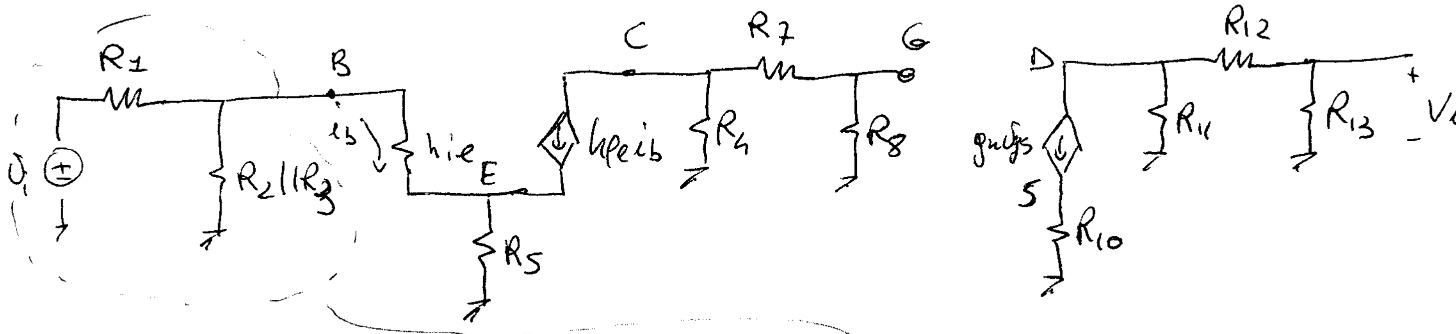
$V_B = V_E + V_\gamma = 3.7V$

$I_2 = \frac{V_{CC} - V_B}{R_2} = 50\mu A$

$I_3 = I_2 - I_B = 4.3103 \times 10^{-5} A$

$R_3 = \frac{V_B}{I_3} = 85840\ \Omega$

$$Q_1 \begin{cases} I_C = 2mA \\ V_{CE} = 5V \\ h_{ie} = 4800\Omega \\ h_{fe} = 300 \end{cases}$$

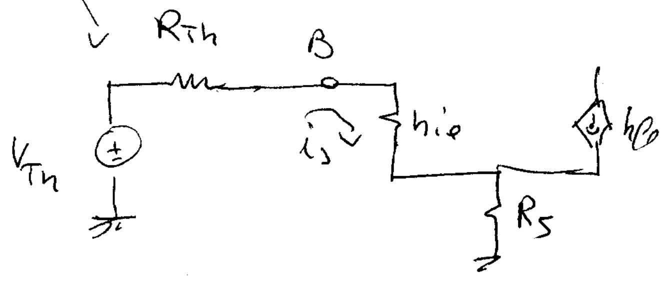


$V_u = (-g_m v_{gs}) \frac{R_{11}}{R_{11} + R_{12} + R_{13}} \cdot R_{13}$

$v_S = g_m v_{gs} R_{10}$

$v_{gs} = \frac{v_g}{1 + g_m R_{10}}$

$v_g = (-h_{fe} i_b) \frac{R_4}{R_4 + R_7 + R_8} \cdot R_8$



$V_{Th} = v_i \frac{R_2 || R_3}{R_1 + R_2 || R_3}$

$R_{Th} = R_1 || R_2 || R_3$

$V_{Th} = (R_{Th} + h_{ie}) i_b + R_5 (h_{fe} + 1) i_b$

$$= \frac{\cancel{v_i R_2 \| R_3}}{\cancel{R_1 + R_2 \| R_3}} V_{Th} \frac{1}{R_{Th} + h_{ie} + R_5(h_{fe}+1)} =$$

$$= V_i \frac{R_2 \| R_3}{R_1 + R_2 \| R_3} \frac{1}{(R_1 \| R_2 \| R_3) + h_{ie} + R_5(h_{fe}+1)}$$

$$\frac{V_u}{V_i} = \overset{2\times 10^{-3}}{(-g_m)} \overset{2333.\overline{3}}{\frac{R_{11} R_{13}}{R_{11} + R_{12} + R_{13}}} \overset{0.5}{\frac{1}{1 + g_m R_{10}}} \overset{300}{(-h_{fe})} \overset{4500}{\frac{R_4 R_8}{R_4 + R_7 + R_8}} \overset{0.985}{\frac{R_2 \| R_3}{R_1 + R_2 \| R_3}} \cdot$$

$$\overset{1.5155\times 10^{-5}}{\frac{1}{(R_1 \| R_2 \| R_3) + h_{ie} + R_5(h_{fe}+1)}} = +47.0258 \quad (33.44\ dB)$$

SERCIZIO B

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

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

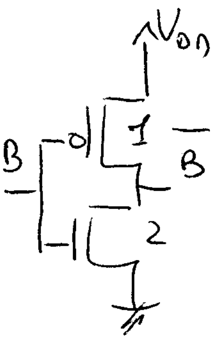
$$= \overline{A}BD + \overline{C}\,\overline{B}D + \overline{A}B\overline{E} + \overline{C}\,\overline{B}\,\overline{E} + \overline{B}\,\overline{C}\,\overline{D} + \overline{C}\,\overline{E} + \overline{A}BC =$$

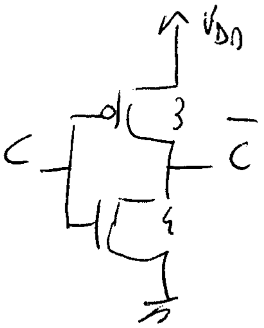
$$= \overline{B}\,\overline{C}(D+\overline{D}+\overline{E}) + \overline{A}BD + \overline{A}B\overline{E} + \overline{C}\,\overline{E} + \overline{A}BC =$$

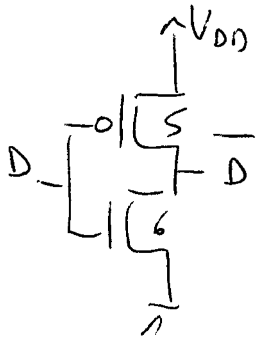
$$= \overline{B}\,\overline{C} + \overline{C}\,\overline{E} + \overline{A}B(D+C+\overline{E}) =$$

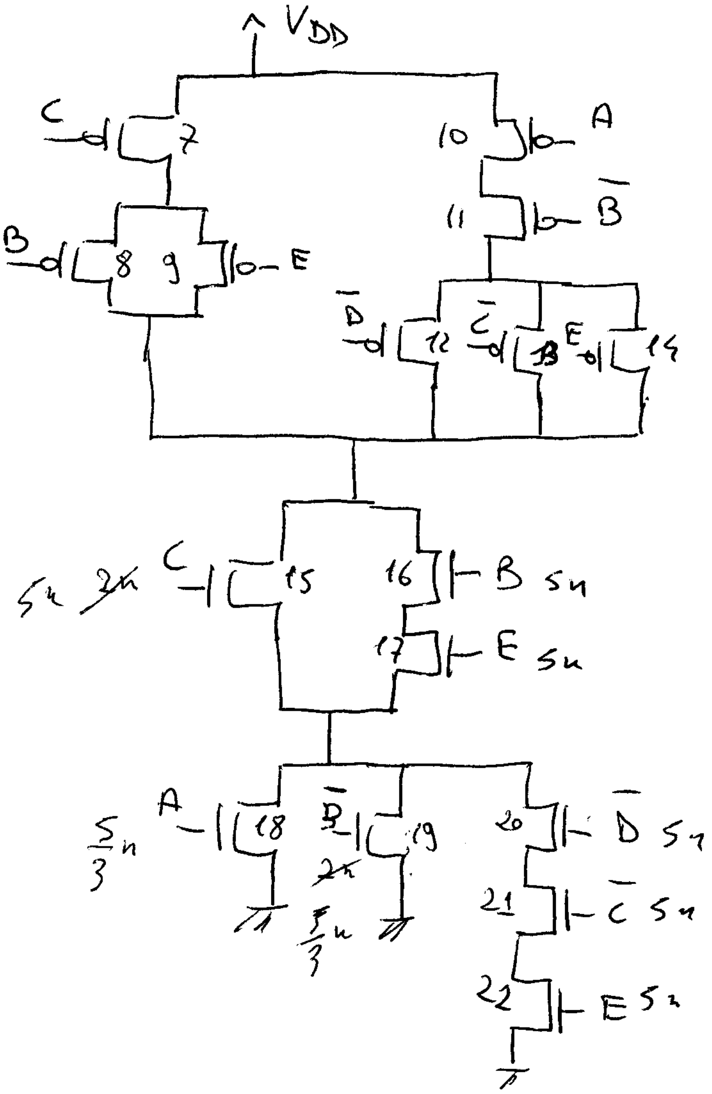
$$= \overline{C}(\overline{B}+\overline{E}) + \overline{A}B(D+C+\overline{E})$$

N. MOS = 8×2 + 3×2 = 22









INVERTER

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

·) PUN

1) SERIE 3 MOS: $Q_{10}-Q_{11}-Q_{12}$; $Q_{10}-Q_{11}-Q_{13}$; $Q_{10}-Q_{11}-Q_{14}$

$\frac{1}{x}+\frac{1}{x}+\frac{1}{x}=\frac{1}{p} \Rightarrow x = 3p = 15 \qquad \left(\frac{W}{L}\right)_{10,11,12,13,14} = 15$

2) SERIE 2 MOS : Q_7-Q_8 ; Q_7-Q_9

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

·) PDN

1) SERIE 5 MOS : $Q_{16}-Q_{17}-Q_{20}-Q_{21}-Q_{22}$

$\frac{1}{z}+\frac{1}{z}+\frac{1}{z}+\frac{1}{z}+\frac{1}{z}=\frac{1}{n} \Rightarrow z = 5n = 10 \quad \left(\frac{W}{L}\right)_{16,17,20,21,22} = 10$

2) SERIE 4 MOS : $Q_{15}-Q_{20}-Q_{21}, Q_{22}$ NON È POSSIBILE PER C e $\bar{C}$

3) SERIE 3 MOS : $Q_{16}-Q_{17}-Q_{19}$ NON È POSSIBILE per B e $\bar{B}$

$Q_{16}-Q_{17}-Q_{18}$ con Q_{16} e Q_{17} già dimensionati

$\frac{1}{k}+\frac{1}{5n}+\frac{1}{5n}=\frac{1}{n}$

$\frac{1}{k}=\frac{1}{n}-\frac{2}{5n}=\frac{3}{5n} \Rightarrow k=\frac{5}{3}n=\frac{10}{3} \quad \left(\frac{W}{L}\right)_{18}=\frac{10}{3}$

$\frac{1}{4}+\frac{3}{3}\left(\frac{L}{W}\right)$

$0.25+\ldots=0.55$

0.55

4) SERIE 2 MOS $Q_{15}-Q_{19}$ e $Q_{15}-Q_{18}$ con Q_{18} già dimensionato

CASO 1 : dimensiono prima Q_{15} e Q_{19}

$\frac{1}{x}+\frac{1}{x}=\frac{1}{n} \Rightarrow x = 2n = 4 \Rightarrow \left(\frac{W}{L}\right)_{15} = \left(\frac{W}{L}\right)_{19} = 4$

NON VERIFIC. TEMPOR.

$Q_{15}-Q_{18}$ NON È VERIFICATA TEMPORIZZAZIONE $\frac{1}{4}+\frac{3}{10}=0.55>\frac{1}{2}$

CASO 2 : dimensiono prima $Q_{15}-Q_{18}$

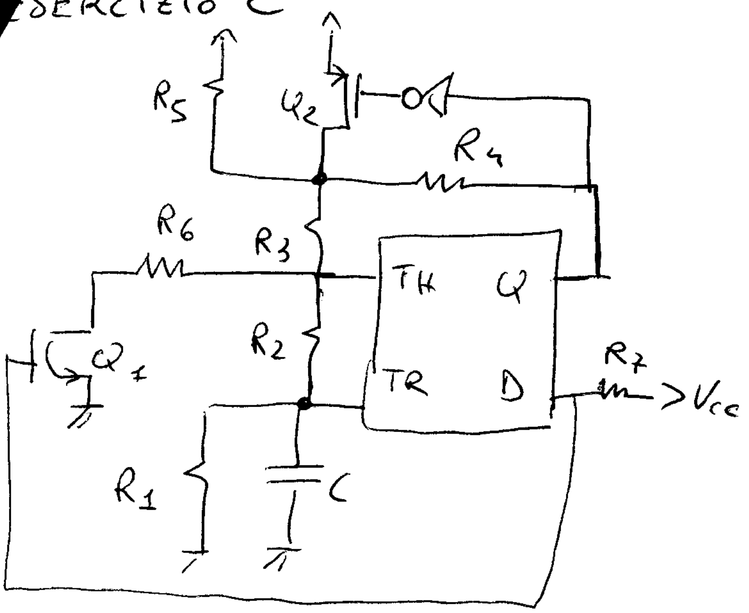
$\frac{1}{x}+\frac{3}{5n}=\frac{1}{n} \Rightarrow \frac{1}{x}=\frac{2}{5n} \Rightarrow x=\frac{10}{2}=5 \quad \left(\frac{W}{L}\right)_{15}=5$

Q_{15} e Q_{19} con Q_{15} già dimensionato

$\frac{1}{y}+\frac{2}{5n}=\frac{1}{n} \Rightarrow \frac{1}{y}=\frac{3}{5n} \Rightarrow y=\frac{10}{3} \Rightarrow \left(\frac{W}{L}\right)_{19}=\frac{10}{3}$

SOLUZIONE ACCETTABILE

ESERCIZIO C



$R_1 = 1.8 k\Omega$

$R_2 = 40 \Omega$

$R_3 = 200 \Omega$

$R_4 = 1920 \Omega$

$R_5 = 1920 \Omega$

$R_6 = 800 \Omega$

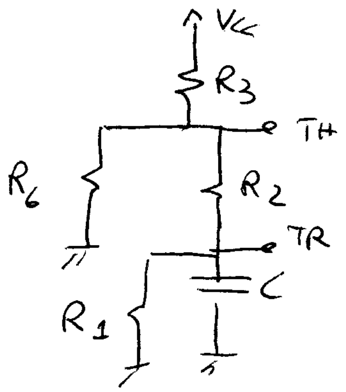
$R_7 = 1 k\Omega$

$C = 47 nF$

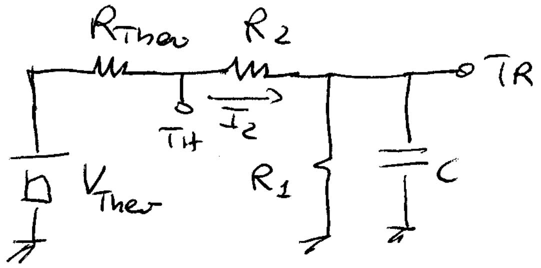
$V_{cc} = 6V$

1) $Q = 1$ $\quad V_{G1} = 6V \quad V_{S1} = \phi V \quad V_{GS1} = 6V > V_T = 1V \Rightarrow Q_1$ ON

$D = HI$ $\quad V_{G2} = \phi V \quad V_{S2} = 6V \quad V_{GS2} = -6V < V_T = -1V \Rightarrow Q_2$ ON



$\Rightarrow$



$$V_{Thev} = V_{cc} \frac{R_6}{R_3 + R_6} = 4.8V$$

$$R_{Thev} = R_3 \| R_6 = 160 \Omega$$

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

$$\underline{V_{f1}} = V_{Thev} \frac{R_1}{R_1 + R_2 + R_{Thev}} = \underline{4.32V}$$

Se $V_{TH} = 4V \quad I_2 = \frac{V_{Thev} - V_{TH}}{R_{Thev}} = 5 mA$

$$V_{i1} < V_{con1} < V_{f1}$$

$$2V < 3.8V < 4.32V$$

Ok

$$\underline{V_{con1}} = V_{TH} - R_2 I_2 = \underline{3.8V}$$

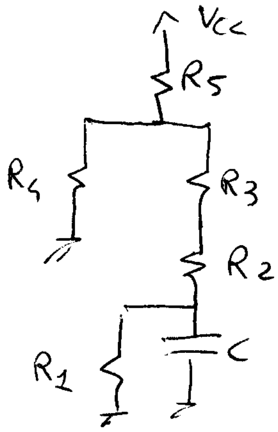
$$R_{V1} = R_1 \| (R_2 + R_{Thev}) = 180 \Omega$$

$$\tau_1 = C R_{V1} = 8.46 \mu s$$

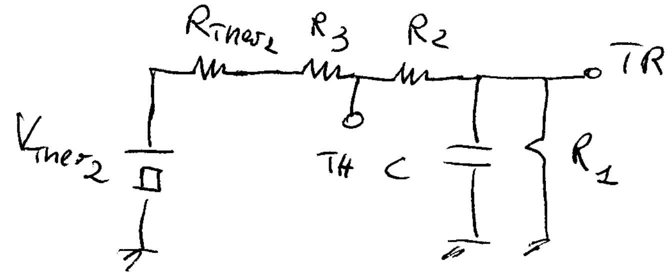
$$T_1 = \tau_1 \ln \left(\frac{V_{i1} - V_{f1}}{V_{con1} - V_{f1}} \right) = 1.2652 \times 10^{-5} s$$

$Q = \emptyset$ $\quad V_{G1} = \emptyset V \quad V_{S1} = \emptyset V \Rightarrow V_{GS1} = \emptyset V < V_T = 1V \Rightarrow Q_1$ off

$D = \emptyset$ $\quad V_{G2} = 6V \quad V_{S2} = 6V \Rightarrow V_{GS2} = \emptyset V > V_T = -1V \Rightarrow Q_2$ off



$\Rightarrow$



$$V_{Thev_2} = \frac{V_{cc} R_4}{R_5 + R_4} = 3V$$

$$R_{Thev_2} = R_4 \| R_5 = 960\,\Omega$$

$\underline{V_{i2}} = V_{con1} = \underline{3.8V}$

$\underline{V_{con2}} = V_{i1} = \underline{2V}$

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

$3.8V > 2V > 1.8V$ OK

$$\underline{V_{f2}} = V_{Thev_2} \frac{R_1}{R_1 + R_2 + R_3 + R_{Thev_2}} = \underline{1.8V}$$

$$R_{v2} = R_1 \| (R_2 + R_3 + R_{Thev_2}) = 720\,\Omega$$

$$\tau_2 = C R_{v2} = 33.84\,\mu s$$

$$T_2 = \tau_2 \ln\left(\frac{V_{i2} - V_{f2}}{V_{con2} - V_{f2}}\right) = 7.79195 \times 10^{-5} s$$

$$T = T_1 + T_2 = 9.05715 \times 10^{-5} s$$

$$\underline{f} = \frac{1}{T} = \underline{\underline{11041 \ Hz}}$$