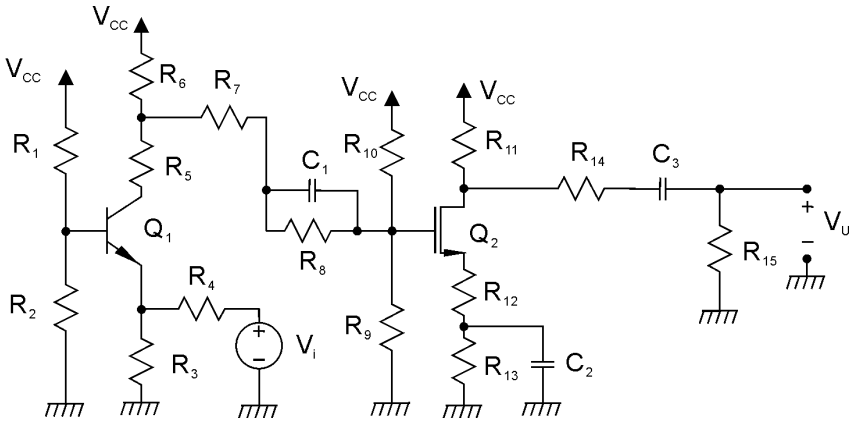
ELETTRONICA DIGITALE

Corso di Laurea in Ingegneria Informatica

Prova scritta del 19 febbraio 2018

Esercizio A

R_2 = 67 kΩ	R_{11} = 4.5 kΩ
R_3 = 15 kΩ	R_{12} = 100 Ω
R_4 = 3750 Ω	R_{13} = 2.4 kΩ
R_5 = 500 Ω	R_{14} = 50 Ω
R_6 = 2.4 kΩ	R_{15} = 15 kΩ
R_7 = 100 Ω	C_1 = 470 nF
R_8 = 7.9 kΩ	C_2 = 68 nF
R_9 = 8 kΩ	C_3= 820 pF
R_{10} =20 kΩ	V_{CC} = 18 V



Q_1 è un transistore BJT BC109B resistivo con $h_{re} = h_{oe}= 0$; Q_2 è un transistore MOS a canale n 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_1 in modo che, in condizioni di riposo, la tensione sul drain di Q_2 sia 9 V. Determinare, inoltre, il punto di riposo dei due transistori e verificare la saturazione di Q_2. (R: R_1 = 105709.7 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 = -2.43)
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}=42.86 Hz, f_{p1}=84.09 Hz, f_{Z2}=975 Hz, f_{p2}=4876 Hz, f_{Z3}=0 Hz, f_{p3}=9928 Hz)

Esercizio B

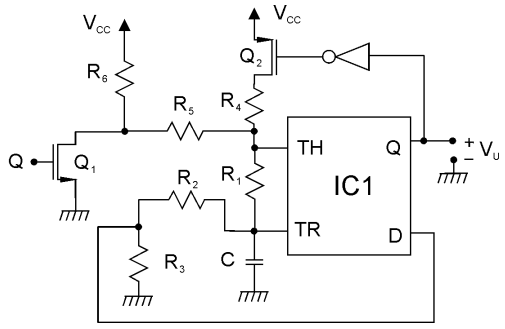
Progettare una porta logica in tecnologia CMOS, utilizzando la tecnica della pull-up network e della pull-down network, che implementi la funzione logica:

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

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 = 14)

Esercizio C

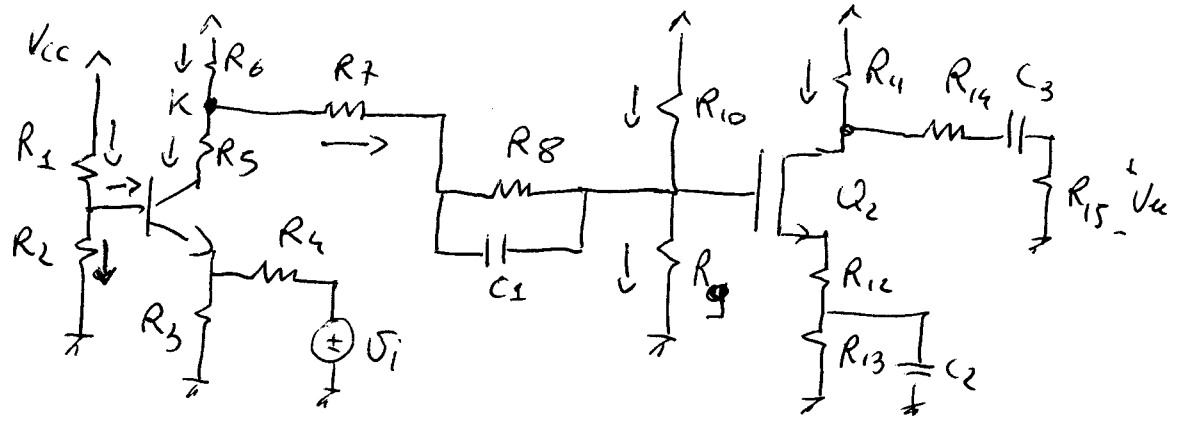
R_1 = 200 Ω	R_5 = 4 kΩ
R_2 = 200 Ω	R_6 = 600 Ω
R_3 = 6.8 kΩ	C = 0.47 μF
R_4 = 1 kΩ	**V_{CC} = 6 V**



Il circuito IC_1 è un NE555 alimentato a **V_{CC} = 6V**, Q_1 ha una R_{on} = 0 e V_T = 1V, 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 = 1307.79 Hz)

APPELLO 19/02/2018

ESERCIZIO A



$R_2 = 6{,}2\ k\Omega$
$R_3 = 15\ k\Omega$
$R_4 = 3750\ \Omega$
$R_5 = 500\ \Omega$
$R_6 = 2{,}4\ k\Omega$
$R_7 = 100\ \Omega$
$R_8 = 2{,}9\ k\Omega$
$R_9 = 8\ k\Omega$
$R_{10} = 20\ k\Omega$
$R_{11} = 4{,}5\ k\Omega$
$R_{12} = 100\ \Omega$
$R_{13} = 2{,}4\ k\Omega$
$R_{14} = 50\ \Omega$
$R_{15} = 15\ k\Omega$
$C_1 = 470\ nF$
$C_2 = 68\ nF$
$C_3 = 820\ pF$
$V_{cc} = 18\ V$

1) Det. R_1 per $V_D = 9V$

$$I_{11} = \frac{V_{cc} - V_D}{R_{11}} = 2\ mA = I_D$$

$I_G = \emptyset \Rightarrow I_D = I_S$

$V_S = I_S (R_{12} + R_{13}) = 5V$

$V_{DS} = V_D - V_S = 9 - 5 = 4V$

Q_2: $\begin{cases} I_D = 2\ mA \\ V_{DS} = 4V \\ V_{GS} = 3V \\ g_m = 2\ \frac{mA}{V} \end{cases}$

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

$$V_{GS} = V_T \overset{\uparrow}{\underset{\text{NMOS}}{\oplus}} \sqrt{\frac{I_D}{k}} = 3V$$

$V_{DS} > V_{GS} - V_T$
$4 > 2 \Rightarrow$ hp verificata

$g_m = 2k(V_{GS} - V_T) = 2\ mA/V$

$V_G = V_{GS} + V_S = 3 + 5 = 8V$

$$I_{10} = \frac{V_{cc} - V_G}{R_{10}} = 0.5\ mA$$

$$I_g = \frac{V_G}{R_g} = 1\ mA$$

$I_7 = -I_{10} + I_g = 0.5\ mA$

$V_K = V_G + I_7(R_7 + R_8) = 12V$

$$I_6 = \frac{V_{cc} - V_K}{R_6} = 2.5\ mA$$

$\circ\ I_6 - I_7 = 2.5\times10^{-3} - 0.5\times10^{-3} = 2\,mA = I_C$

$V_C = V_K - R_5 I_5 = 12 - 1 = 11\,V$

$Q_1 : \begin{cases} I_C = 2\,mA \\ V_{CE} = 5\,V \\ I_B = 6.896\,\mu A \\ h_{ie} = 4800\,\Omega \\ h_{fe} = 300 \end{cases}$

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

$V_E = I_C (R_3 \| R_4) = 6\,V$

$V_{CE} = V_C - V_E = 11 - 6 = 5\,V$

$\Rightarrow h_{FE} = 290$; $h_{ie} = 4800\,\Omega$; $h_{fe} = 300$

$I_B = \frac{I_C}{h_{FE}} = 6.89655\,\mu A \Rightarrow$ hp verificata

$V_B = V_E + V_\gamma = 6.7\,V$

$I_2 = \frac{V_B}{R_2} = 0.1\,mA$

$I_1 = I_2 + I_B = 106.89655\,\mu A$

$R_1 = \frac{V_{cc} - V_B}{I_1} = \underline{105709.677\,\Omega}$

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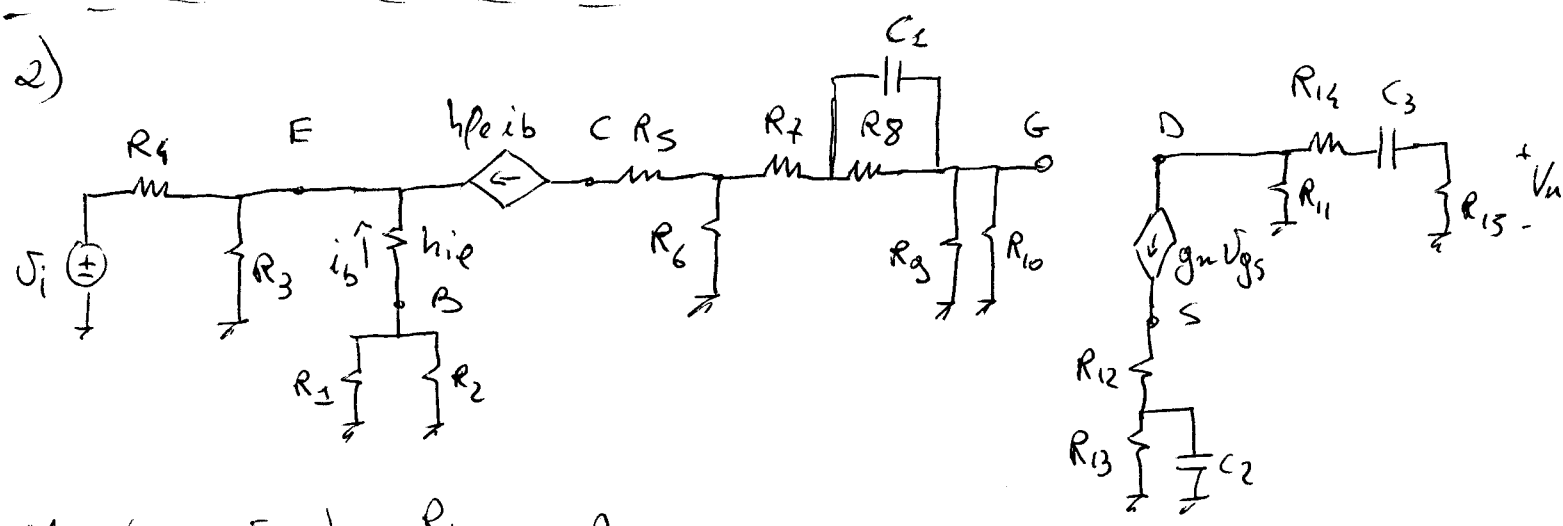
2)

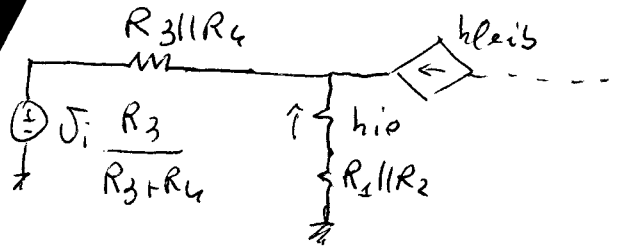


$V_u = (-g_m V_{gs}) \frac{R_{11}}{R_{11} + R_{14} + R_{15}} R_{15}$

$V_s = (g_m V_{gs}) R_{12}$

$V_{gs} = V_g - (g_m V_{gs}) R_{12} = \frac{V_g}{1 + g_m R_{12}}$

$V_g = (-h_{fe} i_b) \frac{R_6}{R_6 + R_7 + (R_9 \| R_{10})} (R_9 \| R_{10})$



$$v_i \frac{R_3}{R_3+R_4} = -(h_{fe}+1)\, i_b (R_3 \| R_4) - i_b (h_{ie} + R_1 \| R_2)$$

$$i_b = -\frac{v_i R_3}{R_3+R_4} \frac{1}{(R_3 \| R_4)(h_{fe}+1) + h_{ie} + R_1 \| R_2}$$

2×10^{-3} $\quad$ 3452.685 $\quad$ $0.8\overline{3}$ $\quad$ 300 $\quad$ 1669.5652 $\quad$ 0.8

$$\frac{V_{ce}}{V_i} = (-g_m)\frac{R_{11} R_{15}}{R_{11}+R_{14}+R_{15}} \frac{1}{1+g_m R_{12}} (-h_{fe}) \frac{R_6 (R_9 \| R_{10})}{R_6 + R_7 + (R_9 \| R_{10})} (-) \frac{R_3}{R_3+R_4} \cdot$$

1.05395×10^{-6}

$$\cdot \frac{1}{(R_3 \| R_4)(h_{fe}+1) + h_{ie} + R_1 \| R_2} = -2.43 \qquad |A_{cs}|_{dB} = 7.71\ dB$$

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3) C_1

$$f_{z1} = \frac{1}{2\pi C_1 R_8} = 42.86\ Hz$$

$$f_{p1} = \frac{1}{2\pi C_1 R_{v1}} = 84.09\ Hz$$

$$R_{v1} = [R_7 + R_6 + (R_9 \| R_{10})] \| R_8 = 4027\ \Omega$$

C_2:

$$f_{z2} = \frac{1}{2\pi C_2 R_{13}} = 975.2\ Hz$$

$$f_{p2} = \frac{1}{2\pi C_2 R_{v2}} = 4876.07\ Hz$$

$$R_{v2} = R_{13} \| \left[R_{12} + \frac{1}{g_m} \right] = 480\ \Omega$$

C_3:

$$f_{z3} = \phi$$

$$f_{p3} = \frac{1}{2\pi C_3 R_{v3}} = 9927.95\ Hz$$

$$R_{v3} = R_{11} + R_{14} + R_{15} = 19550\ \Omega$$

ESERCIZIO B

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

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

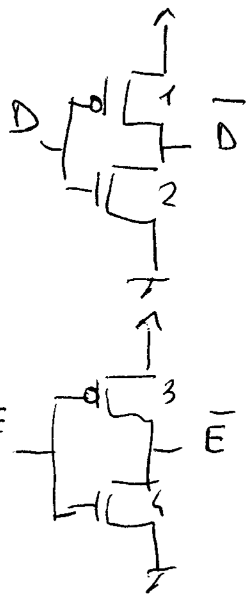
$$= \bar{A}\bar{B} + \bar{A}\bar{C} + \bar{B}\bar{C}D + \bar{C}D + \bar{B}E + \bar{C}E + BE + A\bar{B} = \; (*)$$

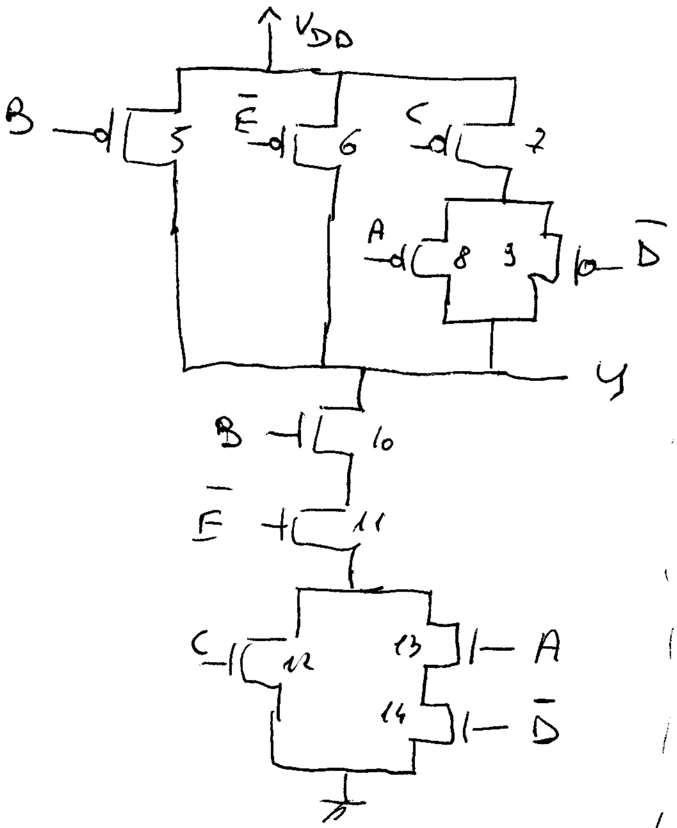
$$= \bar{A}\bar{B} + \bar{A}\bar{C} + \bar{C}D + E + A\bar{B} =$$

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

NMOS = 10 + 4 = 14

(*) Raccogliendo i termini in modo diverso si ottiene, (*) $(\bar{B} + BE) = (\bar{B} + E)$





·) INVERTER

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

·) PUN

$$Q_7 - Q_9 \text{ oppure } Q_7 - Q_8 \Rightarrow \frac{1}{x} + \frac{1}{x} = \frac{1}{p} \Rightarrow x = 2p = 10 = \left(\frac{W}{L}\right)_{7,8,9}$$

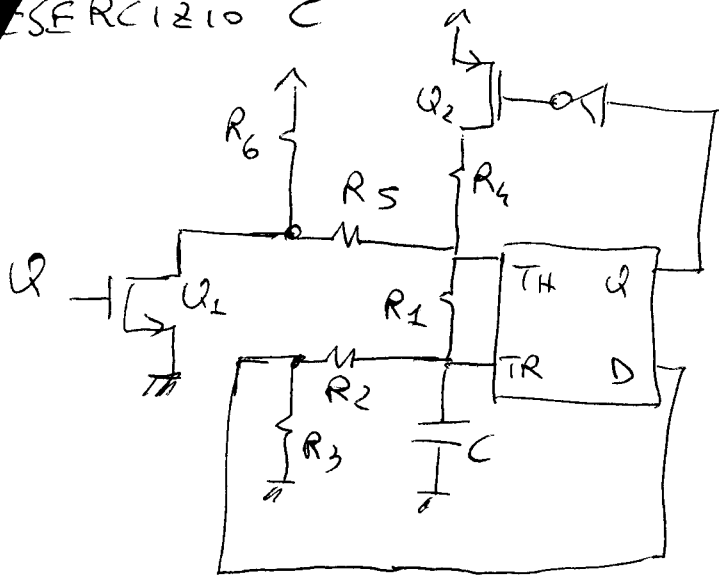
$$\left(\frac{W}{L}\right)_5 = \left(\frac{W}{L}\right)_6 = p = 5$$

·) PDN

$$Q_{10} - Q_{11} - Q_{13} - Q_{14} \Rightarrow \frac{1}{x} + \frac{1}{x} + \frac{1}{x} + \frac{1}{x} = \frac{1}{n} \Rightarrow x = 4n = 8 = \left(\frac{W}{L}\right)_{10,11,13,14}$$

$$Q_{10} - Q_{11} - Q_{12} \rightarrow \frac{1}{y} + \frac{2}{4n} = \frac{1}{n} \Rightarrow y = 2n = 4 = \left(\frac{W}{L}\right)_{12}$$

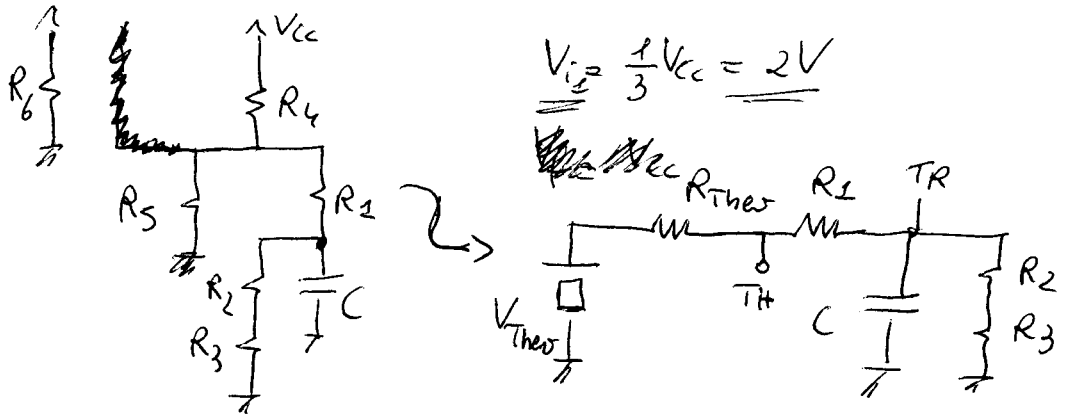
ESERCIZIO C



$R_1 = 200\,\Omega$
$R_2 = 200\,\Omega$
$R_3 = 6.8\,K\Omega$
$R_4 = 1\,K\Omega$
$R_5 = 4\,K\Omega$
$R_6 = 600\,\Omega$
$C = 0.47\,\mu F$
$V_{CC} = 6V$

$Q = 1 \Rightarrow V_{G2} = 0 \quad V_{S2} = V_{CC} \Rightarrow V_{GS2} = -6V < V_T = -1V \Rightarrow Q_2$ ON

DHI $\quad V_{G1} = V_{CC} \quad V_{S1} = 0 \Rightarrow V_{GS1} = 6V > V_T = 1V \Rightarrow Q_1$ ON



$V_{i_1} = \frac{1}{3} V_{CC} = 2V$

$$\left.\begin{aligned} V_{Thev} &= V_{CC}\,\frac{R_5}{R_4+R_5} = 4.8V \\ R_{thev} &= R_4 \| R_5 = 800\,\Omega \end{aligned}\right\} \Rightarrow V_{R_1} = V_{Thev}\,\frac{(R_2+R_3)}{R_{Thev}+R_1+R_2+R_3} = 4.2V$$

$$\left.\begin{aligned} V_{TH} &= \frac{2}{3} V_{CC} = 4V \\ I_1 &= \frac{V_{Thev}-V_{TH}}{R_{Thev}} = 1\,mA \end{aligned}\right\} \Rightarrow V_{con_1} = V_{TH} - R_1 I_1 = 3.8V$$

$V_{i_1} < V_{con_1} < V_{R_1}$
$2 < 3.8 < 4.2$

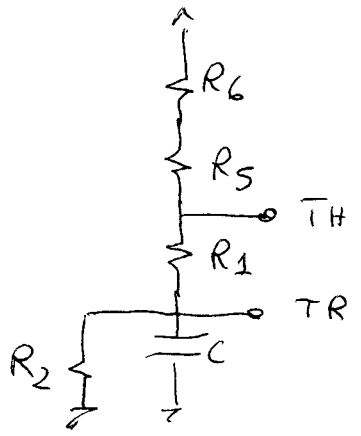
$R_{V1} = (R_2+R_3) \| (R_1+R_{thev}) = 875\,\Omega$

$\tau_1 = R_{V1} C = 411.25\,\mu s$

$T_1 = \tau_1 \ln\left(\frac{V_{i_1}-V_{R_1}}{V_{con_1}-V_{R_1}}\right) = 701.0765\,\mu s$

$=0 \Rightarrow V_{G2} = V_{CC} \quad V_{S2} = V_{CC} \quad V_{GS2} = 0 > V_T = -1V \Rightarrow Q_2$ OFF

$D=\phi \quad V_{G1} = \phi \quad V_{S1} = \phi \quad V_{GS1} = \phi < V_T = 1V \Rightarrow Q_1$ OFF



$V_{i2} = V_{con1} = 3.8V \quad V_{con2} = V_{i1} = 2V$

$$V_{R2} = V_{CC} \frac{R_2}{R_2+R_1+R_5+R_6} = 0.24\ V$$

$V_{i2} > V_{con2} > V_{R2}$

$3.8 > 2 > 0.24$

$R_{V2} = R_2 \,||\, [R_1+R_5+R_6] = 192\ \Omega$

$\tau_2 = C R_{V2} = 90.24\ \mu s$

$$T_2 = \tau_2 \ln\left(\frac{V_{i2}-V_{R2}}{V_{con2}-V_{R2}}\right) = 63.569\ \mu s$$

$T = T_1 + T_2 = 764.647\ \mu s$

$$f = \frac{1}{T} = \underline{1307.79\ Hz}$$