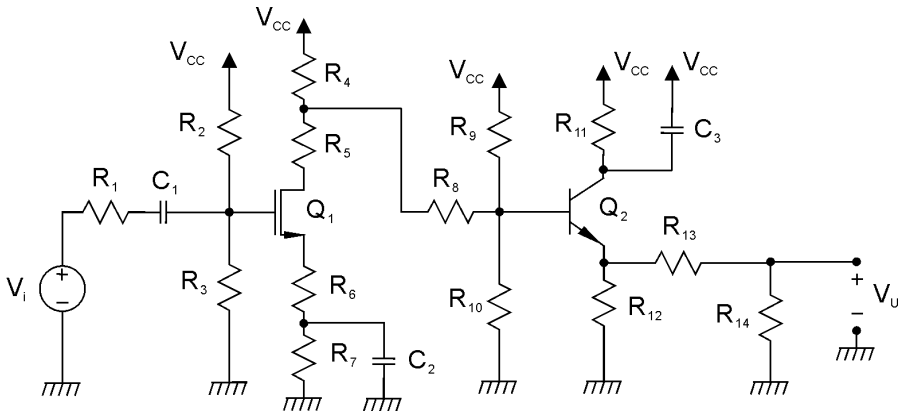
ELETTRONICA DIGITALE

Corso di Laurea in Ingegneria Informatica

Prova scritta del 29 giugno 2017

Esercizio A

R_1 = 50 Ω	R_{11} = 2 kΩ
R_2 = 40 kΩ	R_{12} = 9 kΩ
R_3 = 20 kΩ	R_{13} = 500 Ω
R_4 = 3 kΩ	R_{14} = 8.5 kΩ
R_5 = 500 Ω	C_1 = 220 nF
R_6 = 50 Ω	C_2 = 47 nF
R_8 = 2.5 kΩ	C_3= 1 μF
R_9 = 16.6 kΩ	V_{CC} = 18 V
R_{10} = 9.7 kΩ	



Q_1 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; Q_2 è un transistore BJT BC109B resistivo con $h_{re} = h_{oe}$= 0.
Con riferimento al circuito in figura:

1) Calcolare il valore della resistenza R_7 in modo che, in condizioni di riposo, la tensione sul collettore di Q_2 sia 14 V. Determinare, inoltre, il punto di riposo dei due transistori e verificare la saturazione di Q_1. (R: R_7 = 1628 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 = - 2.59)
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}=0 Hz; f_{p1}=54 Hz; f_{z2}=2080 Hz; f_{p2}=8003 Hz; $f_{z3}=f_{p3}$)

Esercizio B

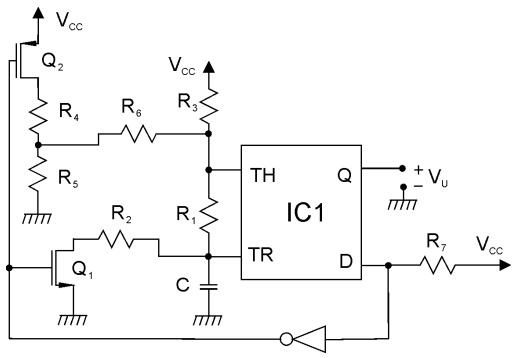
Progettare una porta logica in tecnologia CMOS, utilizzando la tecnica della pull-up network e della pull-down network, che implementi la funzione logica:

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

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.

Esercizio C

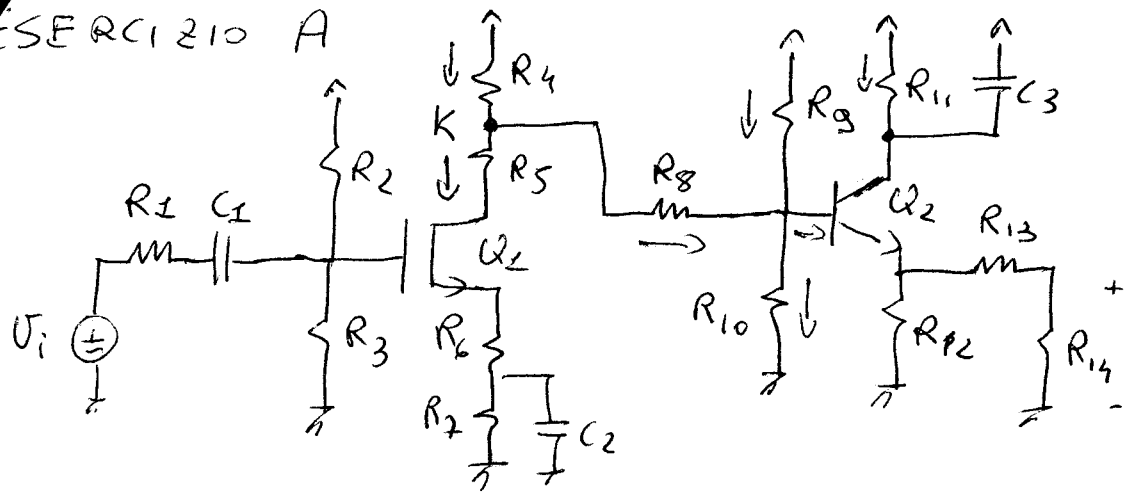
R_1 =1 kΩ	R_6 = 1 kΩ
R_2 = 1 kΩ	R_7 = 10 kΩ
R_3 = 2.6 kΩ	C = 470 nF
R_4 = 500 Ω	V_{CC} = 6 V
R_5 = 2 kΩ	



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 ha una R_{on} = 0 e V_T = - 1V e l'inverter è ideale. Determinare la frequenza del segnale di uscita del multivibratore in figura. (R: f = 2727 Hz)

APPELLO 29/06/2017

ESERCIZIO A



$R_1 = 50\,\Omega$
$R_2 = 40\,K\Omega$
$R_3 = 20\,K\Omega$
$R_4 = 3\,K\Omega$
$R_5 = 500\,\Omega$
$R_6 = 50\,\Omega$
$R_8 = 2.5\,K\Omega$
$R_9 = 16.6\,K\Omega$
$R_{10} = 9.2\,K\Omega$
$R_{11} = 2\,K\Omega$
$R_{12} = 9\,K\Omega$
$R_{13} = 500\,\Omega$
$R_{14} = 8.5\,K\Omega$
$C_1 = 220\,nF$
$C_2 = 47\,nF$
$C_3 = 1\,\mu F$
$V_{cc} = 18\,V$
$K = 0.5\,\frac{mA}{V^2}$

1) Det R_7 per $V_C = 14\,V$

$$I_{11} = \frac{V_{cc} - V_C}{R_{11}} = 2\,mA = I_{C2}$$

hp: $I_{B2} << I_{C2} \Rightarrow I_{E2} \simeq I_{C2}$

$$V_E = I_{C2} \cdot \left[R_{12} \,||\, (R_{13} + R_{14}) \right] = 9\,V$$

$$V_{CE} = 14 - 9 = 5\,V$$

$\Rightarrow h_{FE} = 290$; $h_{ie} = 4800\,\Omega$; $h_{re} = 3ee$

$$I_B = \frac{2 \times 10^{-3}}{290} = 6.896\,\mu A$$

$$V_B = V_E + V_\gamma = 9.7\,V$$

$$I_9 = \frac{V_{cc} - V_B}{R_9} = 0.5\,mA$$

$$I_{10} = \frac{V_D}{R_{10}} = 1\,mA$$

$$I_8 = I_{10} + I_B - I_9 = 5.06896 \times 10^{-4}\,A$$

$$V_K = V_B + R_8 I_8 = 10.967\,V$$

$$I_4 = \frac{V_{cc} - V_K}{R_4} = 2.344\,mA$$

$$I_5 = I_4 - I_8 = 1.837\,mA = I_D = I_S \quad \text{perché } I_G = \phi$$

Q_2: $\begin{cases} I_C = 2\,mA \\ V_{CE} = 5\,V \\ I_B = 6.896\,\mu A \end{cases}$

$V_D = V_K - R_5 I_5 = 10.04856\ V$ (2)

$$V_{GS} = V_T + \sqrt{\frac{I_D}{K}} = 2.917\ V$$

$$V_G = V_{CC}\frac{R_3}{R_2+R_3} = 6\ V$$

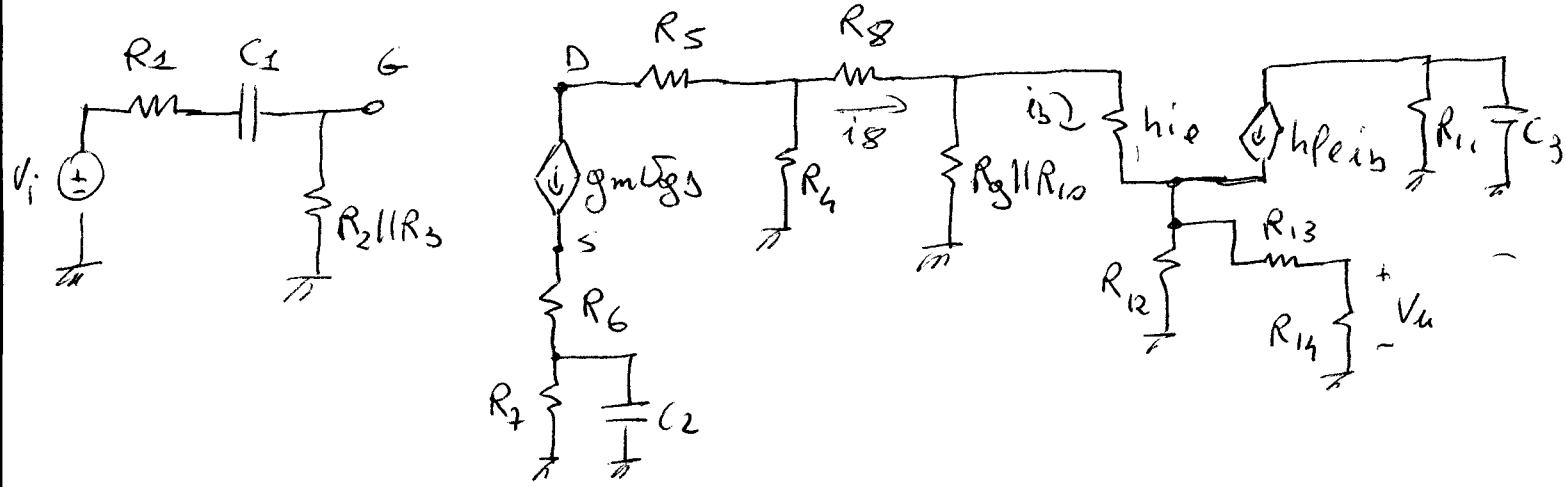
$$V_S = V_G - V_{GS} = 3.083\ V$$

$$V_S = I_D(R_6+R_7) \Rightarrow \underline{R_7 = \frac{V_S}{I_D} - R_6 = 1627.98\ \Omega}$$

$$V_{DS} = 6.9655\ V > V_{GS} - V_T = 1.917\ V$$

$$g_m = 2K(V_{GS}-V_T) = 1.917\ \frac{mA}{V}$$

Q_1 { $I_D = 1.832\ mA$; $V_{DS} = 6.9655\ V$; $V_{GS} = 2.917\ V$; $g_m = 1.917\times10^{-3}\ \frac{A}{V}$



$$V_o = (h_{fe}+1)\, i_b \frac{R_{12}}{R_{12}+R_{13}+R_{14}} \cdot R_{14}$$

$$i_b = i_8 \frac{R_g \| R_{10}}{(R_g \| R_{10}) + h_{ie} + [R_{12} \| (R_{13}+R_{14})](h_{fe}+1)}$$

$$i_8 = (-g_m V_{gs}) \frac{R_4}{R_4 + \{R_8 + R_g \| R_{10} \| [h_{ie} + (R_{12} \| (R_{13}+R_{14}))(h_{fe}+1)]}$$

$= (g_m v_{gs}) R_6$

$$v_{gs} = v_g - g_m v_{gs} R_6 = \frac{v_g}{1 + g_m R_6}$$

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

$$\frac{V_u}{V_i} = \underbrace{(h_{fe}+1)}_{301} \underbrace{\frac{R_{12} R_{14}}{R_{12} + R_{13} + R_{14}}}_{4250} \cdot \underbrace{\frac{R_9 \| R_{10}}{(R_9 \| R_{10}) + h_{ie} + [R_{12} \| (R_{13} + R_{14})](h_{fe}+1)}}_{4.4839 \times 10^{-3}} \cdot$$

$$\cdot \underbrace{(-g_m)}_{1.912 \times 10^{-3}} \underbrace{\frac{R_4}{R_4 + R_8 + R_9 \| R_{10} \| \{ h_{ie} + [R_{12} \| (R_{13} + R_{14})](h_{fe}+1) \}}}_{0.2587} \cdot$$

$$\cdot \frac{1}{1 + g_m R_6} \cdot \frac{R_2 \| R_3}{(R_2 \| R_3) + R_1} = -2.586 \qquad \left| \frac{V_u}{V_i} \right| = 8.254 \text{ dB}$$

0.9125 $\quad$ 0.996

C_1: $f_{z1} = 0$ Hz

$$f_{p1} = \frac{1}{2\pi C_1 R_{v1}} = 54.05 \text{ Hz}$$

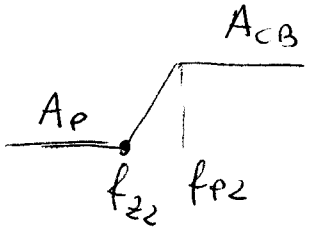
$$R_{v1} = R_1 + R_2 \| R_3 = 13383.\overline{3}\ \Omega$$

C_2: $f_{z2} = \frac{1}{2\pi C_2 R_7} = 2080.05$ Hz

$$f_{p2} = \frac{1}{2\pi C_2 R_{v2}} = 8003.75 \text{ Hz}$$

$$R_{v2} = R_7 \| \left(R_6 + \frac{1}{g_m} \right) = 423.086\ \Omega$$

C_3: $f_{z3} = f_{p3}$



$$|A_P| = |A_{CB}| \frac{f_{z2}}{f_{p2}} =$$

$$= 0.672$$

$$|A_P| = -3.45 \text{ dB}$$

ESERCIZIO B

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

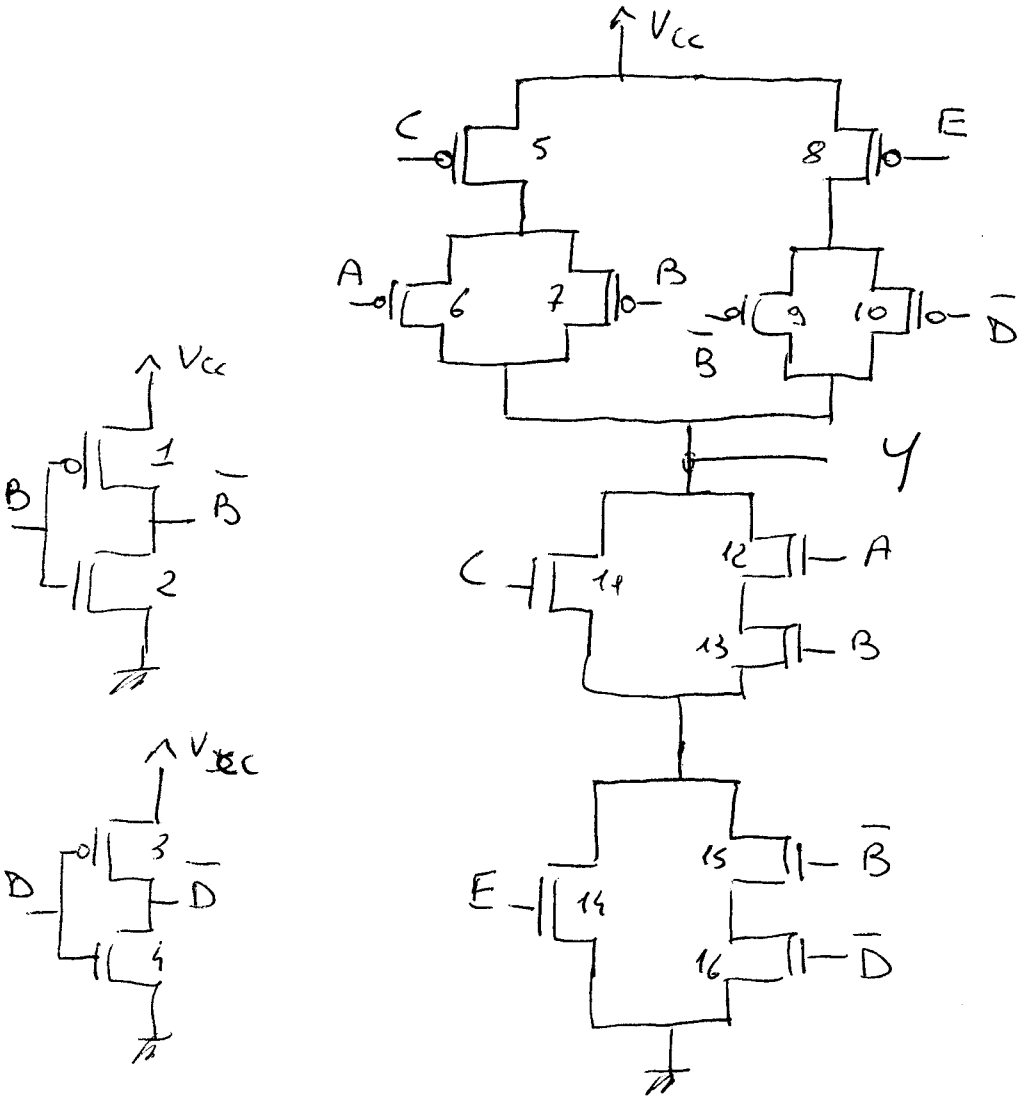
$$= (AB + \bar{C} + D\bar{E})(\bar{A} + \bar{B}) + B\bar{E} + D\bar{E} =$$

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

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

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

N MOS = 12 + 4 = 16



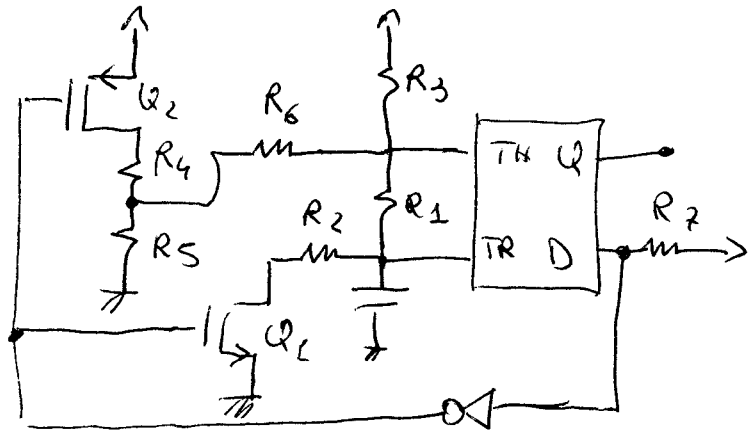
·) INVERTER : $\left(\frac{W}{L}\right)_{1,3} = p = 5 \qquad \left(\frac{W}{L}\right)_{2,4} = n = 2$

·) PUN : $Q_5 - Q_6$; $Q_5 - Q_7$; $Q_8 - Q_9$; $Q_{8-10} \Rightarrow \left(\frac{W}{L}\right)_{5,6,7,8,9,10} = 2p = 10$

·) PDN : $Q_{12}, Q_{13}, Q_{15}, Q_{16}$ NON È POSSIBILE

$Q_{12} - Q_{13} - Q_{14}$ oppure $Q_{11} - Q_{15} - Q_{16} \Rightarrow \left(\frac{W}{L}\right)_{11,12,13,14,15,16} = 3n = 6$

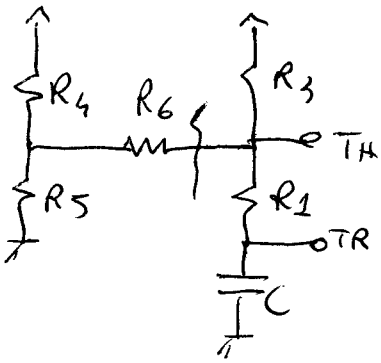
ESERCIZIO C



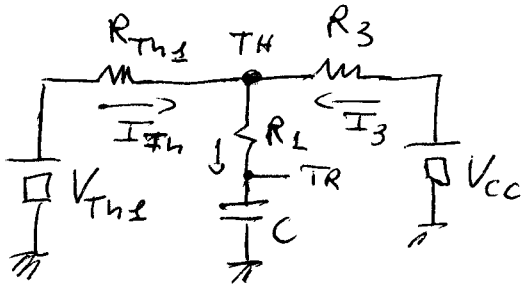
$R_1 = 1k\Omega$
$R_2 = 1k\Omega$
$R_3 = 2.6k\Omega$
$R_4 = 500\,\Omega$
$R_5 = 2k\Omega$
$R_6 = 1k\Omega$
$R_7 = 10\,k\Omega$
$C = 470\,nF$

1) $Q = 1$, $D = HI$ $\Big\}$ $V_{G1} = 0$ $V_{S1} = 0$ $V_{GS1} = 0 < V_{T_1} \Rightarrow Q_1$ off $V_{CC} = 6V$

$V_{G2} = 0$ $V_{S2} = V_{CC}$ $V_{GS2} = -V_{CC} = -6V < V_{T_2} = -1 \Rightarrow Q_2$ on



$\Rightarrow$



$$V_{Th1} = V_{CC}\frac{R_5}{R_4+R_5} = 4.8V$$

$$R_{Th1} = (R_4 \| R_5) + R_6 = 1400\,\Omega$$

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

$$V_{f_1} = V_{Th1}\frac{R_3}{R_3+R_{Th1}} + V_{CC}\frac{R_{Th1}}{R_{Th1}+R_3} = 3.12 + 2.1 = 5.22V$$

$V_{TH} = 4V$

$$I_{Th} = \frac{V_{Th1}-V_{TH}}{R_{Th1}} = 5.714\times10^{-4}\,A$$

$$I_3 = \frac{V_{CC}-V_{TH}}{R_3} = 7.692\times10^{-4}\,A$$

$$I_1 = I_{Th} + I_3 = 1.34\,mA$$

$$V_{con1} = V_{TH} - R_1 I_1 = 2.659V$$

$V_{i_1} < V_{con1} < V_{f_1}$

$2 < 2.659 < 5.22$

$R_{V1} = R_1 + (R_{Th1} \parallel R_3) = 1910\ \Omega$

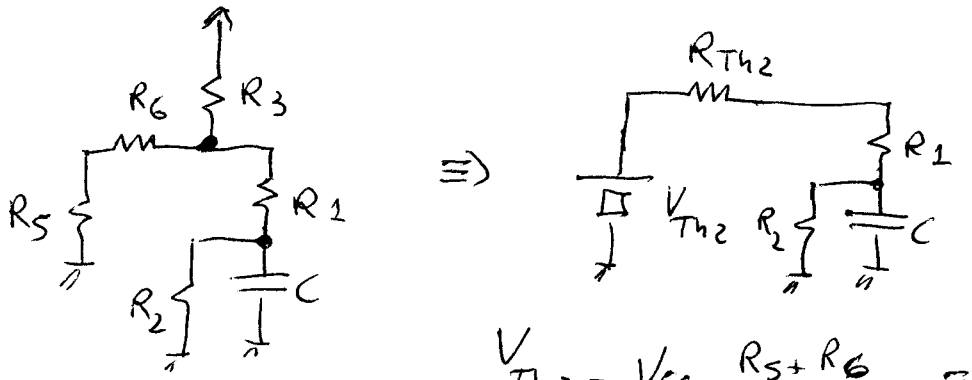
$\tau_1 = R_{V1} C_1 = 897.2\ \mu s$

$T_1 = \tau_1 \ln\left(\frac{V_{i1} - V_{f1}}{V_{con1} - V_{f1}}\right) = 2.05558 \times 10^{-4}\ s$

2) $Q=0$, $D=0$:

$V_{G1} = V_{cc}$ $V_{S1} = 0$ $V_{GS1} = V_{cc} > V_T = 1V \Rightarrow Q_1$ ON

$V_{G2} = V_{cc}$ $V_{S2} = V_{cc}$ $V_{GS2} = 0 > V_T(-1) \Rightarrow Q_2$ OFF



$V_{Th2} = V_{cc} \frac{R_5 + R_6}{R_5 + R_6 + R_3} = 3.214\ V$

$R_{Th2} = R_3 \parallel (R_5 + R_6) = 1392.86\ \Omega$

$V_{i2} = V_{con2} = 2.659\ V$

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

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

$2.659 > 2 > 0.947$

$V_{f2} = V_{Th2} \frac{R_2}{R_{Th2} + R_1 + R_2} = 0.947\ V$

$R_{V2} = R_2 \parallel (R_1 + R_{Th2}) = 705.26\ \Omega$

$\tau_2 = R_{V2} \cdot C = 3.3147 \times 10^{-4}\ s$

$T_2 = \tau_2 \ln\left(\frac{V_{i2} - V_{f2}}{V_{con2} - V_{f2}}\right) = 1.6111 \times 10^{-4}\ s$

$T = T_1 + T_2 = 3.6666 \times 10^{-4}\ s$

$f = \frac{1}{T} = 2727.31\ Hz$