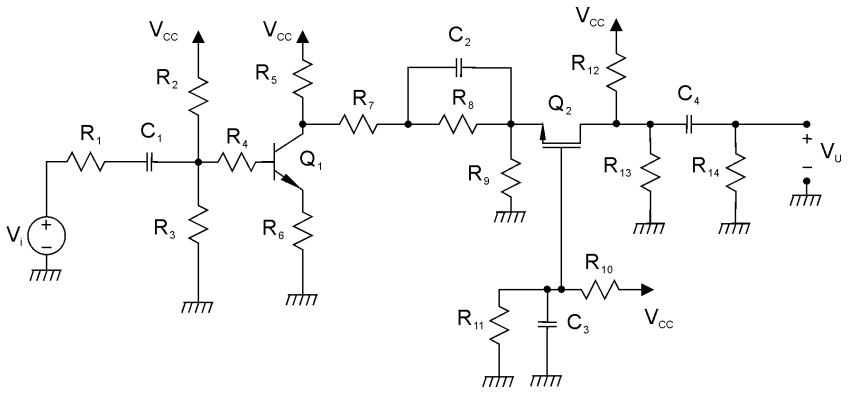
ELETTRONICA DIGITALE

Corso di Laurea in Ingegneria Informatica

Prova scritta del 13 settembre 2016

Esercizio A

R_1 =50 Ω	R_{11} = 300 kΩ
R_2 = 30 kΩ	R_{12} = 2.8 kΩ
R_4 = 5 kΩ	R_{13} = 22 kΩ
R_5 = 27.5 kΩ	R_{14} = 30 kΩ
R_6 = 1 kΩ	C_1 = 3.3 nF
R_7 = 50 Ω	C_2 = 330 nF
R_8 = 450 Ω	C_3= 1μF
R_9 = 19.5 kΩ	C_4= 470 nF
R_{10} = 200 kΩ	V_{CC} = 18 V



Q_1 è un transistore BJT BC109B resistivo con $h_{re} = h_{oe}= 0$, Q_2è 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_3 in modo che, in condizioni di riposo, la tensione sul drain di Q_2 sia 11 V. Determinare, inoltre, il punto di riposo dei due transistori e verificare la saturazione di Q_2. (R: R_3 = 5448 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 = -2.1)
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}=10500 Hz; f_{z2}=1071 Hz; f_{p2}=1089 Hz; $f_{z3}=f_{p3}$; f_{z4}=0 Hz; f_{p4}=10.4 Hz;)

Esercizio B

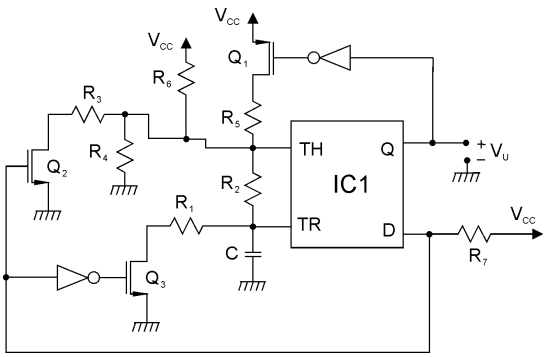
Progettare una porta logica in tecnologia CMOS, utilizzando la tecnica della pull-up network e della pull-down network, che implementi la funzione logica:

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

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.

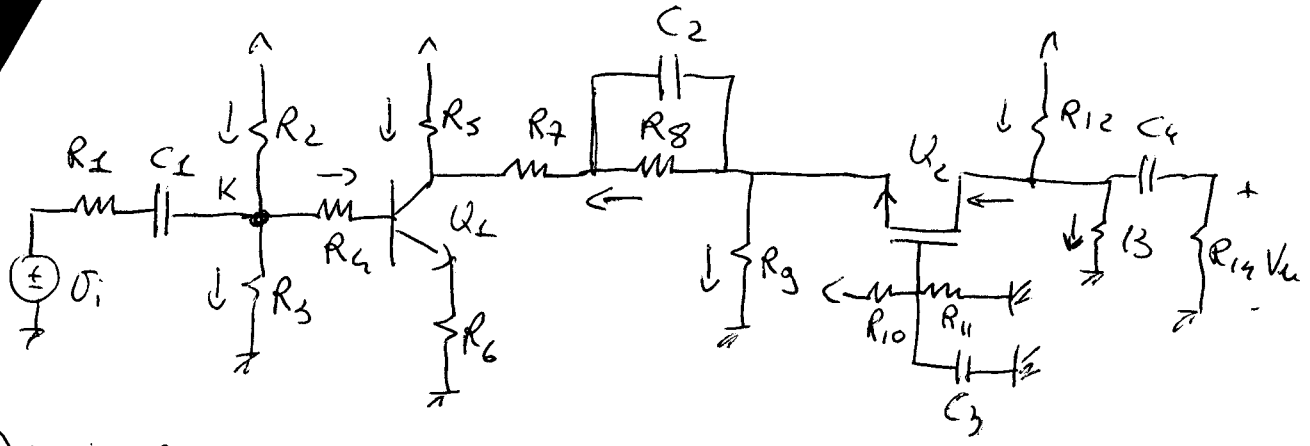
Esercizio C

R_1 =100 Ω	R_6 = 2 kΩ
R_2 = 750 Ω	R_7 = 1 kΩ
R_3 = 10 kΩ	C = 680 nF
R_4 = 10 kΩ	**V_{CC} = 6 V**
R_5 = 2 kΩ	



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 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. (R: f = 1912 Hz)

APPELLO 13/09/2016



$R_1 = 50\,\Omega$
$R_2 = 30\,K\Omega$
$R_4 = 5\,K\Omega$
$R_5 = 22.5\,K\Omega$
$R_6 = 1\,K\Omega$
$R_7 = 50\,\Omega$
$R_8 = 450\,\Omega$
$R_9 = 19.5\,K\Omega$
$R_{10} = 200\,K\Omega$
$R_{11} = 300\,K\Omega$
$R_{12} = 2.8\,K\Omega$
$R_{13} = 2.2\,K\Omega$
$R_{14} = 30\,K\Omega$
$C_1 = 3.3\,nF$
$C_2 = 330\,nF$
$C_3 = 1\,\mu F$
$C_4 = 420\,nF$
$V_{cc} = 18\,V$
$K = 0.5\,\frac{mA}{V^2}$

1) Det. R_3 per $V_{D2} = 11\,V$

$$I_{12} = \frac{V_{cc} - V_{D2}}{R_{12}} = 2.5\,mA$$

$$I_{13} = \frac{V_{D2}}{R_{13}} = 0.5\,mA$$

$$I_{D2} = I_{12} - I_{13} = 2\,mA$$

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

$$V_{GS} = V_T + \sqrt{\frac{I_D}{K}} = 3\,V$$

$I_G = 0 \Rightarrow V_G = V_{cc}\frac{R_{11}}{R_{11}+R_{10}} = 10.8\,V$

$V_S = V_G - V_{GS} = 7.8\,V$

$V_{DS} = V_D - V_S = 11 - 7.8 = 3.2\,V > (V_{GS} - V_T) = 2\,V \Rightarrow$ hp: OK

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

$$I_g = \frac{V_S}{R_g} = \frac{7.8}{19.5 \times 10^3} = 0.4\,mA$$

$I_8 = I_S - I_g = 1.6\,mA$

$V_{C1} = V_S - (R_7 + R_8)I_8 = 7\,V$

$$I_S = \frac{V_{cc} - V_{C1}}{R_5} = 0.4\,mA$$

$I_{C1} = I_S + I_8 = 2\,mA$

hp: $I_B \ll I_C \Rightarrow I_E \simeq I_C$

$V_{E1} = R_6 I_C = 2\,V$

$$Q_2 = \begin{cases} I_D = 2\,mA \\ V_{DS} = 3.2\,V \\ V_{GS} = 3\,V \\ g_m = 2\,\frac{mA}{V} \end{cases}$$

$= V_{C_1} - V_{E_1} = 7 - 2 = 5V$

h_{FE}

... usare $\beta = 290$ $\quad h_{fe} = 300$

$h_{ie} = 4800\,\Omega$

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

$I_{B_1} = \frac{I_{C_1}}{h_{FE}} = 6.896\,\mu A \quad \ll I_C \Rightarrow h_p$ ok

$V_{B1} = V_E + V_\gamma = 2.7\,V$

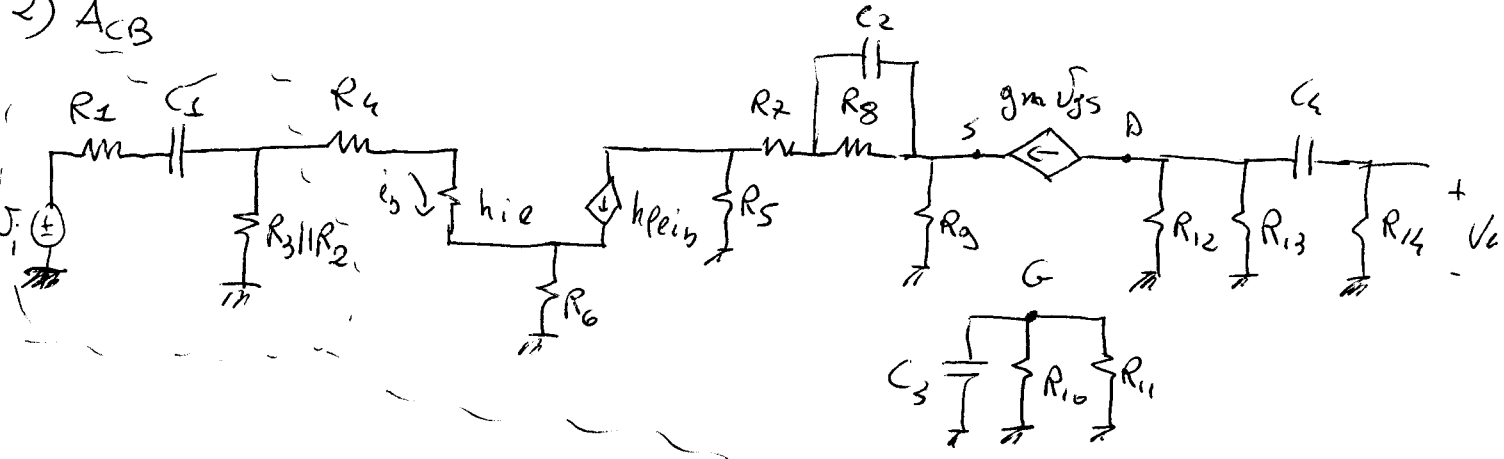
$V_K = V_{B1} + R_4 I_{B1} = 2.7345\,V$

$I_{R2} = \frac{V_{CC} - V_K}{R_2} = 0.50885\,mA$

$I_{R3} = I_{R2} - I_{B1} = 0.501954\,mA$

$R_3 = \frac{V_K}{I_{R3}} = 5447.686\,\Omega$

2) A_{CB}

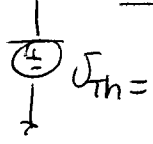


$V_u = (-g_m V_{gs})(R_{12} \| R_{13} \| R_{14})$

$V_g = \phi$

$V_s = (-h_{fe} i_b) \frac{R_5}{R_5 + R_7 + \left(R_9 \| \frac{1}{g_m}\right)} \left(R_9 \| \frac{1}{g_m}\right)$

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



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

$V_i \frac{R_2 \| R_3}{R_1 + R_2 \| R_3} = \left[(R_1 \| R_2 \| R_3) + R_4 + h_{ie}\right] i_b + R_6 (h_{fe} + 1) i_b$

$i_b = \frac{V_i \frac{R_2 \| R_3}{R_1 + R_2 \| R_3}}{(R_1 \| R_2 \| R_3) + R_4 + h_{ie} + R_6 (h_{fe} + 1)}$

(2×10^{-3}) 2293.34 300 478.154 3.18248×10^{-6}

$$= +g_m\left(R_{12}\|R_{13}\|R_{14}\right)(-h_{fe})\frac{R_5\left(R_g\|\frac{1}{g_m}\right)}{R_5+R_7+\left(R_g\|\frac{1}{g_m}\right)}\frac{\frac{R_2\|R_3}{R_1+R_2\|R_3}}{\left(R_1\|R_2\|R_3\right)+R_4+h_{ie}+R_6(h_{fe}+1)} =$$

$$= -2.0944$$

$$\left|\frac{V_u}{V_i}\right|_{dB} = 6.42\ dB$$

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3) POLI E ZERI

C_1: $f_{z1} = \phi$ Hz

$$f_{p1} = \frac{1}{2\pi C_1 R_{V1}} = 10500.33 \text{ Hz}$$

$$R_{V1} = R_1+\left\{R_2\|R_3\|\left[R_4+h_{ie}+R_6(h_{fe}+1)\right]\right\} = 4593.07\ \Omega$$

C_2: $f_{z2} = \frac{1}{2\pi C_2 R_8} = 1071.75$ Hz

$$f_{p2} = \frac{1}{2\pi C_2 R_{V2}} = 1088.96 \text{ Hz}$$

$$R_{V2} = R_8\|\left\{R_5+R_7+\left(R_g\|\frac{1}{g_m}\right)\right\} = 442.89\ \Omega$$

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

C_4: $f_{z4} = \phi$

$$f_{p4} = \frac{1}{2\pi R_{V4} C_4} = 10.42 \text{ Hz}$$

$$R_{V4} = \left(R_{12}\|R_{13}\right)+R_{14} = 32483.87\ \Omega$$

$\overline{(\bar{A}+\bar{B})(C\bar{D}+\bar{E})+(\overline{\bar{A}+B})(\bar{C}+\bar{E})+\bar{D}(\overline{A+\bar{B}})+\bar{D}E}$ = (4)

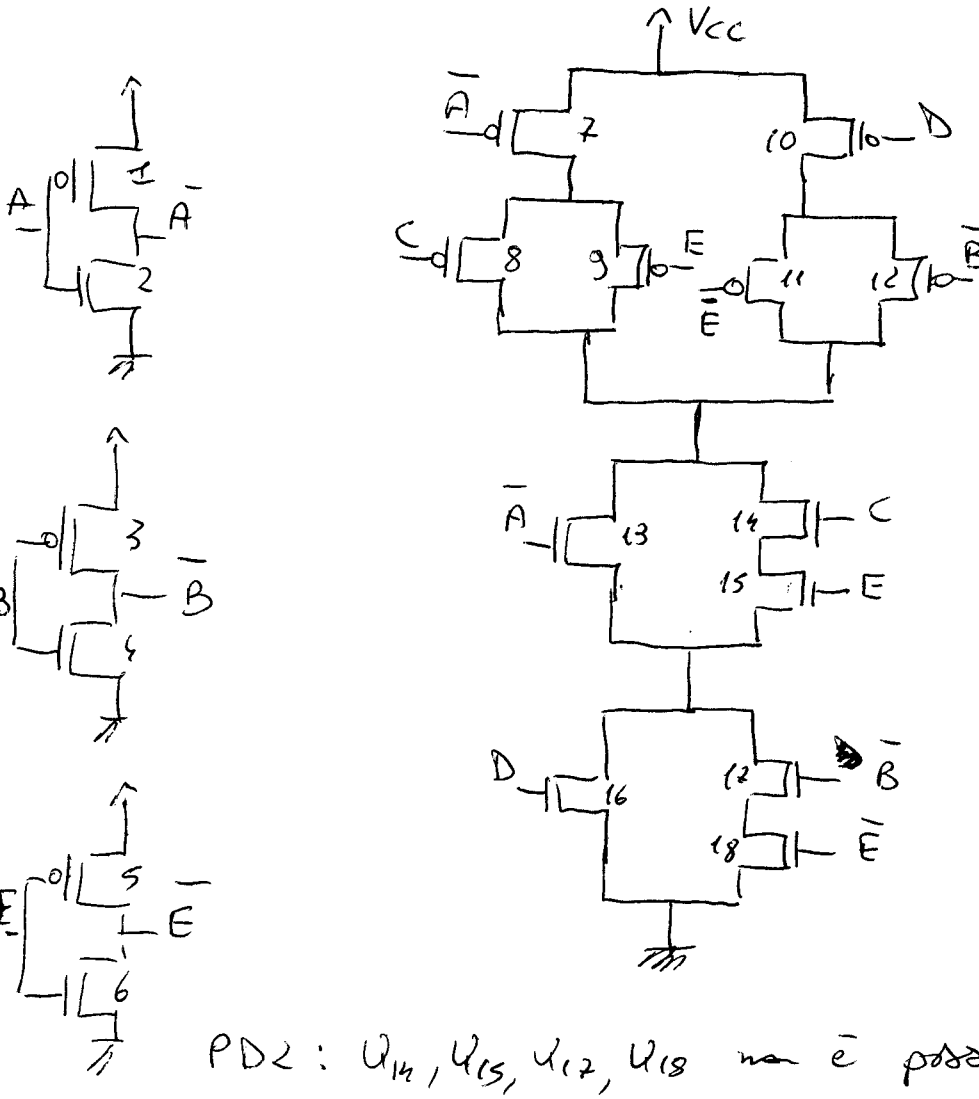
$= AB(\bar{C}+\bar{D}+\bar{E})+A\bar{B}(\bar{C}+\bar{E})+\bar{D}\bar{A}B+\bar{D}E =$

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

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

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

N. MOS = 12+6 = 18



$\left(\frac{W}{L}\right)_1 = \left(\frac{W}{L}\right)_3 = \left(\frac{W}{L}\right)_5 = p = 5$

$\left(\frac{W}{L}\right)_2 = \left(\frac{W}{L}\right)_4 = \left(\frac{W}{L}\right)_6 = n = 2$

) PUN

$Q_7 - Q_8$
$Q_7 - Q_9$
$Q_{10} - Q_{11}$
$Q_{10} - Q_{12}$

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

$\left(\frac{W}{L}\right)_{2,8,9,10,11,12} = 10$

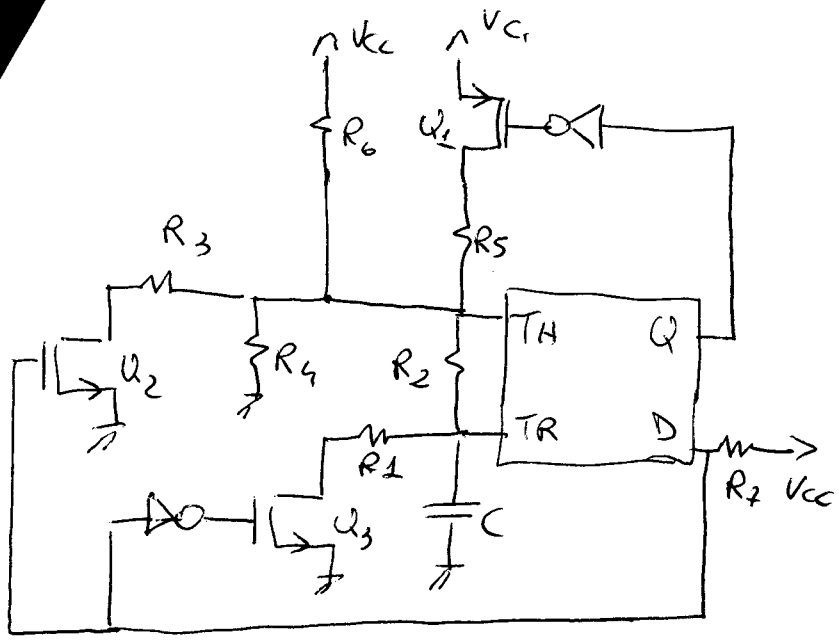
PDZ: $Q_{14}, Q_{15}, Q_{17}, Q_{18}$ não é possível

$Q_{14} - Q_{15} - Q_{16}$
$Q_{13} - Q_{17} - Q_{18}$

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

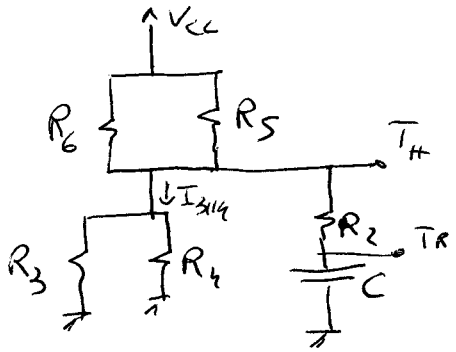
$\left(\frac{W}{L}\right)_{13,14,15,16,17,18} = 6$

RC1 210 C



$R_1 = 100\,\Omega$
$R_2 = 750\,\Omega$
$R_3 = 10\,K\Omega$
$R_4 = 10\,K\Omega$
$R_5 = 2K\Omega$
$R_6 = 2K\Omega$
$R_7 = 1\,K\Omega$
$C = 680\,nF$
$V_{cc} = 6\,V$

$Q = 1$
$D = HI$
$\Rightarrow$ Q_1 ON, Q_2 ON, Q_3 OFF



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

$V_{f_1} = V_{cc} \dfrac{R_3 \| R_4}{R_3 \| R_4 + R_5 \| R_6} = 5\,V$

Per $V_{TH} = \frac{2}{3} V_{cc} = 4\,V$

$I_{5\|6} = \dfrac{V_{cc} - V_{TH}}{R_5 \| R_6} = 2\,mA$

$I_{3\|4} = \dfrac{V_{TH}}{R_3 \| R_4} = 0.8\,mA$

$I_{R2} = I_{5\|6} - I_{3\|4} = 1.2\,mA$

$V_{cor_1} = V_{TH} - R_2 I_{R2} = 3.1\,V$

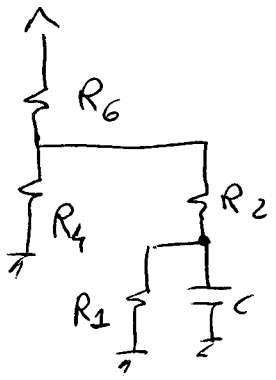
$V_i < V_{cor} < V_f \Rightarrow$ CORRUTTA

$R_{VC_1} = R_2 + [R_5 \| R_6 \| R_3 \| R_4] = 1583.\overline{3}\,\Omega$

$\tau_1 = R_{VC_1} C_1 = 1.07\overline{6}\,ms$

$T_1 = \tau_1 \ln\left(\dfrac{V_{i_1} - V_{f_1}}{V_{cor_1} - V_{f_1}}\right) = 0.4918\,ms$

$=0$ } = Q_1 OFF
$=0$ } = Q_2 OFF
Q_3 ON



$V_{i2} = V_{con2} = 3.1V$

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

$$V_{f2} = V_{cc} \frac{R_4 \| (R_1+R_2)}{[R_4 \| (R_1+R_2)] + R_6} \cdot \frac{R_1}{R_1+R_2}$$

0.281 $\quad$ 0.117

$= 0.1987\ V$

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

$R_{VC_2} = R_1 \| [R_2 + R_4 \| R_6] = 96.03\ \Omega$

$\tau_2 = R_{VC_2} \cdot C = 65.298\ \mu s$

$$T_2 = \tau_2 \ln\left(\frac{V_{i2} - V_{f2}}{V_{con2} - V_{f2}}\right) = 31.124\ \mu s$$

$T = T_1 + T_2 = 0.5229\ ms$

$f = \frac{1}{T} = \underline{1912.4\ Hz}$