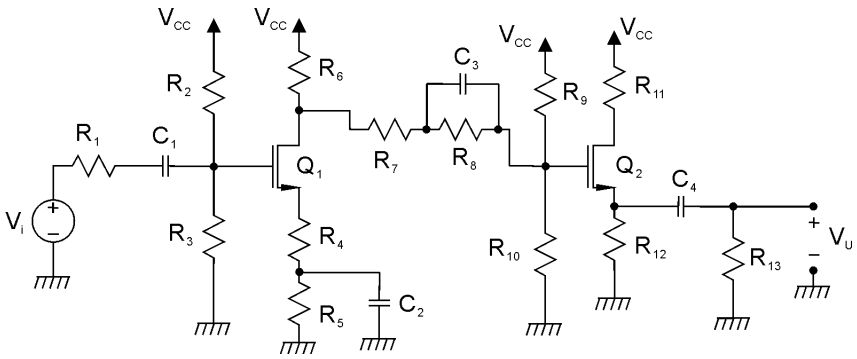
ELETTRONICA DIGITALE

Corso di Laurea in Ingegneria Informatica

Prova scritta del 09 giugno 2015

Esercizio A

R_1 =50 Ω	R_{11} = 4 kΩ
R_2 = 200 kΩ	R_{12} = 2500 Ω
R_3 = 100 kΩ	R_{13} = 10 kΩ
R_4 = 100 Ω	C_1 = 220 nF
R_5 = 1400 Ω	C_2 = 33 nF
R_6 = 3600 Ω	C_3= 100 nF
R_7 = 100 Ω	C_4= 680 pF
R_9 = 20 kΩ	V_{CC} = 18 V
R_{10} = 8 kΩ	



Q_1 e Q2 sono transistori MOS a canale n resistivi, 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_8 in modo che, in condizioni di riposo, la tensione sul drain di Q_2 sia 10 V. Determinare, inoltre, il punto di riposo dei due transistori e verificarne la saturazione. (R: R_8 = 1900 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 = -2.9)
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} = 10.84 Hz; f_{z2} = 3444.91 Hz; f_{p2} = 11483 Hz; f_{z3} = 837.66 Hz; f_{p3} = 1006.72 Hz; f_{z4} = 0 Hz; f_{p4} = 22468.9 Hz)

Esercizio B

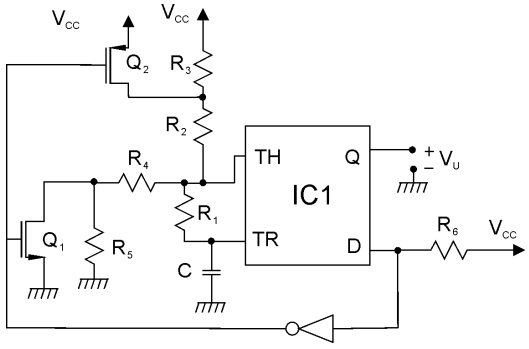
Progettare una porta logica in tecnologia CMOS, utilizzando la tecnica della pull-up network e della pull-down network, che implementi la funzione logica:

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

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.

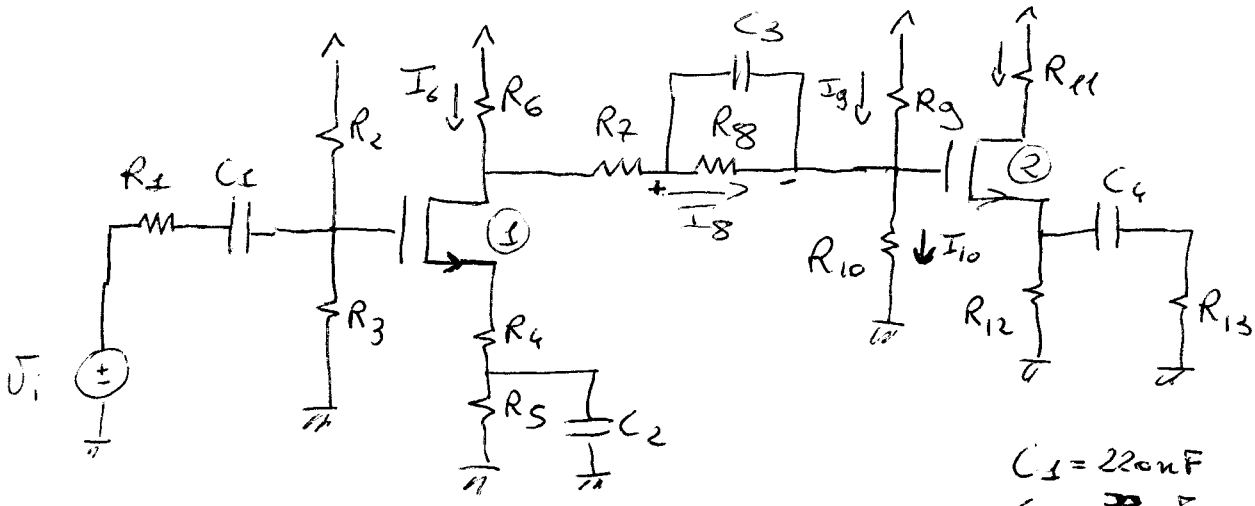
Esercizio C

R_1 =3 kΩ	R_5 = 20 kΩ
R_2 = 4 kΩ	R_6 = 1 kΩ
R_3 = 5 kΩ	C = 100 nF
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 e Q_2 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 = 2008 Hz).

APPELLO 08/06/2015



$R_1 = 50\,\Omega$
$R_2 = 200\,K\Omega$
$R_3 = 100\,K\Omega$
$R_4 = 100\,\Omega$
$R_5 = 1400\,\Omega$
$R_6 = 3600\,\Omega$
$R_7 = 100\,\Omega$
$R_8 = 20\,K\Omega$
$R_9 = 8\,K\Omega$
$R_{10} = 4\,K\Omega$
$R_{11} = 2500\,\Omega$
$R_{12} = 10\,K\Omega$
R_{13}
$V_{CC} = 18\,V$
$K = 0.5\ \frac{mA}{V^2}$

$C_1 = 220\,nF$
$C_2 = 33\,nF$
$C_3 = 100\,nF$
$C_4 = 680\,pF$

1) Determine R_9 per $V_{D2} = 10\,V$

$$I_{D2} = I_{S2} = \frac{V_{CC} - V_{D2}}{R_{11}} = \frac{18-10}{4000} = 2\,mA$$

$$V_{GS2} = V_T + \sqrt{\frac{I_{D2}}{K}} = 1 + 2 = 3\,V$$

$$V_{S2} = I_{S2} R_{12} = 5\,V$$

$$V_{G2} = V_{GS2} + V_{S2} = 3 + 5 = 8\,V$$

$$V_{DS2} = 10 - 5 = 5\,V$$

$$\begin{cases} V_{DS2} > V_{GS2} - V_T \\ 5 > 3 - 1 = 2 \end{cases} \Rightarrow \text{VERIFICA OK}$$

Q_2:
$I_{D2} = 2\,mA$
$V_{DS2} = 5\,V$
$V_{GS2} = 3\,V$
$g_m = 2K(V_{GS2} - V_T) = 2 \times 10^{-3}\ \frac{A}{V}$

$$I_g = \frac{V_{CC} - V_{G2}}{R_9} = \frac{18-8}{20 \times 10^3} = 0.5\,mA$$

$$I_{10} = \frac{V_{G2}}{R_{10}} = \frac{8}{8000} = 1\,mA$$

$$I_8 = I_{10} - I_g = 10^{-3} - 0.5 \times 10^{-3} = 0.5\,mA$$

$$V_{G1} = V_{CC} \frac{R_3}{R_2 + R_3} = 18\,\frac{100 \times 10^3}{300 \times 10^3} = 6\,V$$

$$I_D = K(V_{GS1} - V_T)^2 = K\left(V_{G1} - V_{S1} - V_T\right)^2 = K\left[6 - (R_4 + R_5) I_{D1} - V_T\right]^2 =$$

$$= 0.5 \times 10^{-3}\left[5 - 1500\, I_{D1}\right]^2 = 0.5 \times 10^{-3}\left[25 + 2.25 \times 10^6\, I_{D1}^2 - 1.5 \times 10^4\, I_{D1}\right] =$$

$$= 0.0125 + 1125\, I_{D1}^2 - 7.5\, I_{D1}$$

$$225\, I_{D1}^2 - 8.5\, I_{D1} + 0.0125 = 0$$

$$I_{D1} = \frac{8.5 \pm \sqrt{72.25 - 56.25}}{2250} = \frac{8.5 \pm 4}{2250} \begin{cases} I_{D1A} = 5.\bar{5}\ mA \\ I_{D1B} = 2\ mA \end{cases}$$

Con $I_{D1} = 5.\bar{5}\ mA$ $V_{S1} = 8.\bar{3}\ V \Rightarrow V_{GS1} < 0$ NON ACCETTABILE

e $I_{D1} = 2\ mA$ $V_{S1} = 3\ V \Rightarrow V_{GS1} = 6 - 3 = 3V > V_T$ OK

$$I_G = I_B + I_{D1} = 0.5 \times 10^{-3} + 2 \times 10^{-3} = 2.5\ mA$$

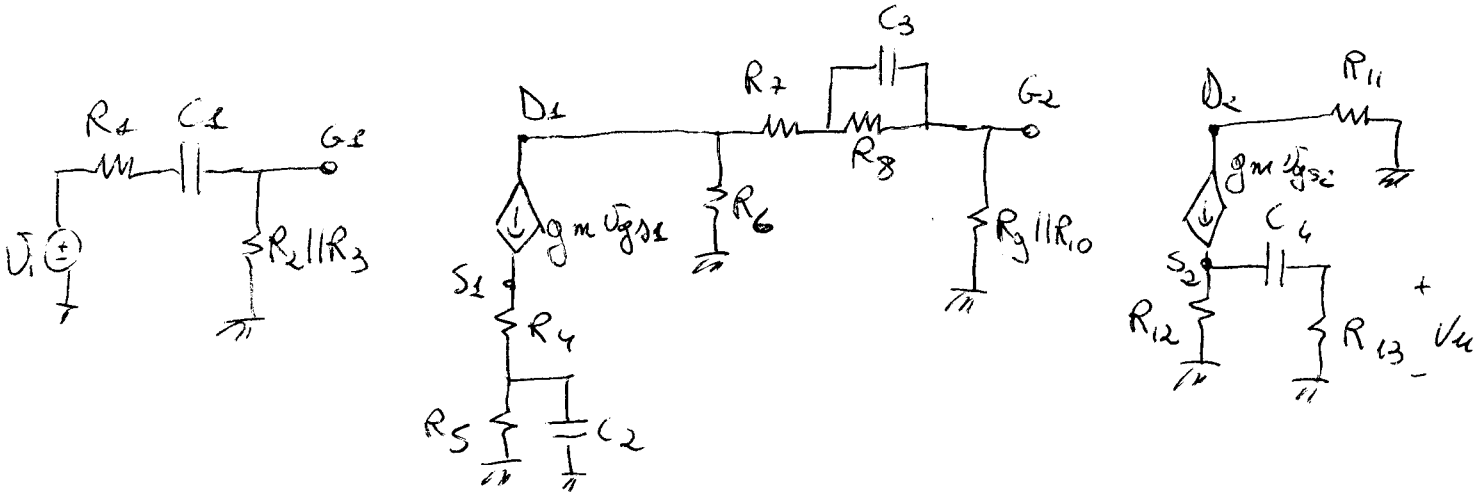
$$V_{D1} = V_{CC} - R_6 I_G = 18 - 3600 \times 2.5 \times 10^{-3} = 9\ V$$

$$V_{DS1} = V_{D1} - V_{S1} = 9 - 3 = 6\ V > V_{GS1} - V_T = 3 - 1 = 2V$$

$$Q_1 : \begin{cases} I_{D1} = 2\ mA \\ V_{DS1} = 6\ V \\ V_{GS1} = 3V \\ g_{m1} = 2K(V_{GS1} - V_T) = 2 \times 10^{-3}\ \frac{A}{V} \end{cases}$$

$$V_{R8} = V_{D1} - R_7 I_B \cong V_{G2} = 9 - 0.05 \cong 8 = 0.95\ V$$

$$R_8 = \frac{V_{R8}}{I_B} = \frac{0.95}{0.5 \times 10^{-3}} = \mathbf{1900\ \Omega}$$



CALCOLO DI A_{CB}

$$V_u = g_m V_{GS2} (R_{12} \| R_{13}) = V_{S2}$$

$$V_{S2} = \frac{g_m (R_{12} \| R_{13}) V_{G2}}{1 + g_m (R_{12} \| R_{13})}$$

$$V_{G2} = \left(-g_m V_{GS1}\right) \frac{R_6}{R_6 + R_7 + (R_9 \| R_{10})} (R_9 \| R_{10})$$

$$V_{S1} = \left(g_m V_{GS1}\right) R_4 = \frac{g_m R_4}{1 + g_m R_4} V_{G1} \quad \Rightarrow \quad V_{GS1} = V_{G1} - g_m R_4 V_{GS1} = \frac{V_{G1}}{1 + g_m R_4}$$

$$V_{G1} = V_i \frac{R_2 \| R_3}{R_1 + R_2 \| R_3}$$

$$\frac{V_u}{V_i} = \underbrace{\frac{g_m (R_{12} \| R_{13})}{1 + g_m (R_{12} \| R_{13})}}_{(0.8)} \left(- g_m \underbrace{\frac{R_6 (R_9 \| R_{10})}{R_6 + R_7 + (R_9 \| R_{10})}}_{(4.370258)}\right) \underbrace{\frac{1}{1 + g_m R_4}}_{(0.83)} \underbrace{\frac{R_2 \| R_3}{R_1 + R_2 \| R_3}}_{(0.99925)}$$

$$= -2.911$$

$$|A_{CB}|_{dB} = 9.282$$

·) POLI E ZERI

C_1: $f_{z1} = \phi$

$$f_{p1} = \frac{1}{2\pi C_1 R_{V1}} = 10.84 \text{ Hz}$$

$$R_{V1} = R_1 + R_2 \| R_3 = 66716.\bar{6}\ \Omega$$

C_2: $f_{z2} = \frac{1}{2\pi C_2 R_5} = 3444.91 \text{ Hz}$

$$f_{p2} = \frac{1}{2\pi C_2 R_{V2}} = 11483.04 \text{ Hz}$$

$$R_{V2} = R_5 \| \left(R_4 + \frac{1}{g_m}\right) = 420\ \Omega$$

$$f_{z3} = \frac{1}{2\pi C_3 R_8} = 837.652\ Hz$$

$$f_{p3} = \frac{1}{2\pi C_3 R_{v3}} = 1006.712\ Hz$$

$$R_{v3} = R_8 \parallel \left[R_6 + R_7 + (R_9 \parallel R_{10}) \right] = 1580.93\ \Omega$$

C_4: $f_{z4} = 0\ Hz$

$$f_{p4} = \frac{1}{2\pi C_4 R_{v4}} = 22468.93$$

$$R_{v4} = \left(\frac{1}{g_m} \parallel R_{12} \right) + R_{13} = 10416.\overline{6}\ \Omega$$

ESERCIZIO B

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

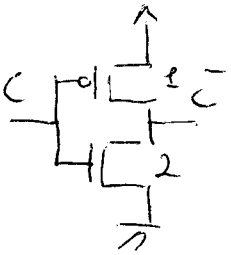
$$= (\overline{A} + \overline{B} + C)(\overline{C}D + \overline{E}) + (\overline{C} + E)(\overline{A} + \overline{B}) + \overline{D}\overline{E} =$$

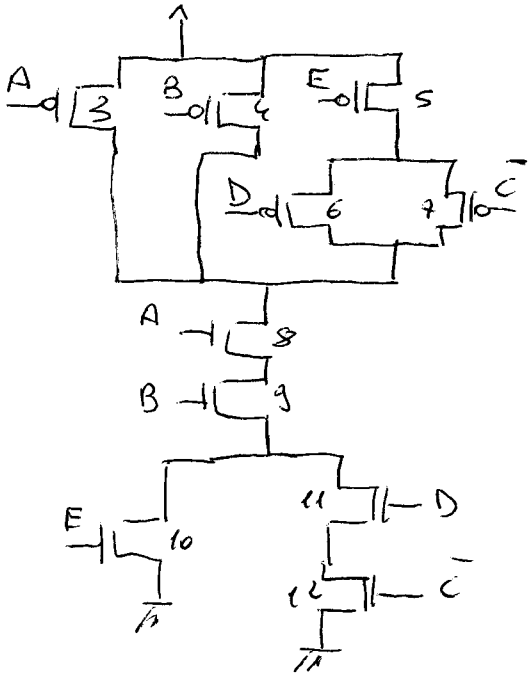
$$= \overline{A}\overline{C}D + \overline{A}\overline{E} + \overline{B}\overline{C}D + \overline{B}\overline{E} + C\overline{E} + \overline{A}\overline{C} + \overline{B}\overline{C} + \overline{A}E + \overline{B}E + \overline{D}\overline{E} =$$

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

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

N. MOSFET = 12





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

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

·) Serie Q_5 - Q_6 oppure Q_5 - Q_7

$\frac{2}{x} = \frac{1}{p} \Rightarrow x = 2p \Rightarrow \left(\frac{W}{L}\right)_5 = \left(\frac{W}{L}\right)_6 = \left(\frac{W}{L}\right)_7 = 2p = 10$

·) $\left(\frac{W}{L}\right)_3 = \left(\frac{W}{L}\right)_4 = p = 5$

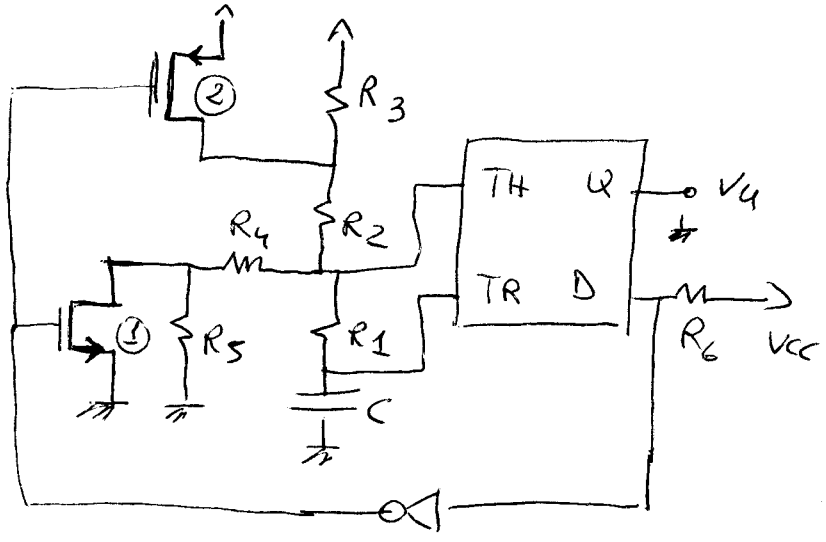
·) Serie Q_8 - Q_9, Q_{11}, Q_{12}

$\frac{4}{x} = \frac{1}{n} \Rightarrow x = 4n \Rightarrow \left(\frac{W}{L}\right)_8 = \left(\frac{W}{L}\right)_9 = \left(\frac{W}{L}\right)_{11} = \left(\frac{W}{L}\right)_{12} = 4n = 8$

·) Serie Q_8, Q_9, Q_{10}

$\frac{1}{x} + \frac{1}{4n} = \frac{1}{n} \Rightarrow \frac{1}{x} = \frac{2}{4n} \Rightarrow x = 2n \Rightarrow \left(\frac{W}{L}\right)_{10} = 2n = 4$

ESERCIZIO C



$V_{cc} = 6V$

$R_1 = 3k\Omega$

$R_2 = 4k\Omega$

$R_3 = 5k\Omega$

$R_4 = 1k\Omega$

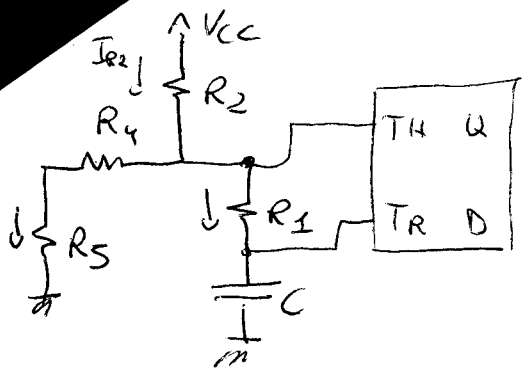
$R_5 = 20k\Omega$

$C = 100\,nF$

·) $Q = 1$

$D = HI \Rightarrow V_{G1} = 0V \Rightarrow Q_1$ OFF

$V_{G2} = 0V \Rightarrow Q_2$ ON



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

$$V_f = V_{CC}\frac{R_4+R_5}{R_2+R_4+R_5} = 5.04\ V$$

$$V_{TH} = \frac{2}{3}V_{CC} = 4V$$

$$I_{R2} = \frac{V_{CC} - \frac{2}{3}V_{CC}}{R_2} = 0.5\ mA$$

$$I_{R4} = \frac{\frac{2}{3}V_{CC}}{R_4+R_5} = 1.9047\times10^{-4}A$$

$$I_{R1} = I_{R2} - I_{R4} = 3.095\times10^{-4}A$$

$$V_{con1} = \frac{2}{3}V_{CC} - R_1 I_{R1} = 3.0714\ V$$

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

$2V < 3.0714V < 5.04V$ OK

$$\tau_1 = C R_{v1}$$

$$R_{v1} = R_1 + R_2 \| (R_4+R_5) = 6360\ \Omega$$

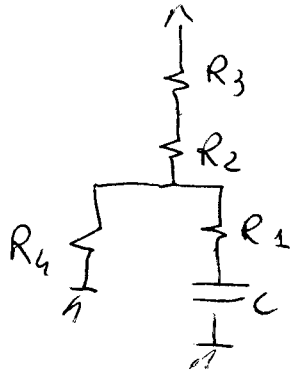
$$\tau_1 = 636\ \mu s$$

$$T_1 = \tau_1 \ln\left(\frac{V_i - V_f}{V_{con1} - V_f}\right) = 2.2636\times10^{-4}\ s$$

·) $Q = \phi$

$D = \phi \Rightarrow V_{G1} = V_{CC} \Rightarrow Q_1$ ON

$V_{G2} = V_{CC} \Rightarrow Q_2$ OFF



$$V_{i2} = V_{con1} = 3.0714\ V$$

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

$$V_{f2} = V_{CC}\frac{R_4}{R_4+R_2+R_3} = 0.6\ V$$

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

$3.0714V > 2V > 0.6V$ OK

$$R_{v2} = R_1 + [(R_2+R_3)\|R_4] = 3900\ \Omega$$

$$\tau_2 = C R_{v2} = 390\ \mu s$$

$$T_2 = \tau_2 \ln\left(\frac{V_{i2} - V_{f2}}{V_{con2} - V_{f2}}\right) = 2.216\times10^{-4}\ s$$

$$T = T_1 + T_2 = 4.980\times10^{-4}\ s$$

$$f = \frac{1}{T} = 2008\ Hz$$