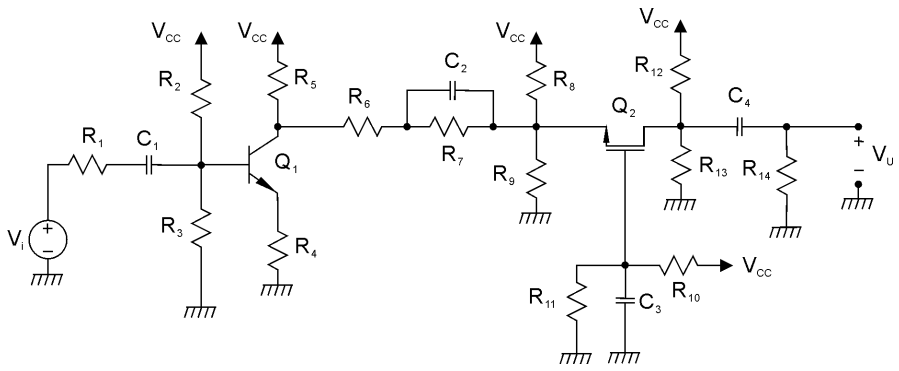
ELETTRONICA DIGITALE

Corso di Laurea in Ingegneria Informatica

Prova scritta del 20 febbraio 2017

Esercizio A

R_1 = 100 Ω	R_{11} = 60 kΩ
R_3 = 80 kΩ	R_{12} = 2 kΩ
R_4 = 1250 Ω	R_{13} = 26 kΩ
R_5 = 21 kΩ	R_{14} = 50 kΩ
R_6 = 100 Ω	C_1 = 2.2 nF
R_7 = 900 Ω	C_2 = 1 μF
R_8 = 18 kΩ	C_3= 1 μF
R_9 = 9 kΩ	C_4 = 330 nF
R_{10} = 30 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 V_{T2} = 1 V con la corrente di drain in saturazione data da $I_D=k(V_{GS}-V_T)^2$ con k = 0.5 mA/V^2.
Con riferimento al circuito in figura:

1) Calcolare il valore della resistenza R_2 in modo che, in condizioni di riposo, la tensione sul drain di Q_2 sia 13 V. Determinare, inoltre, il punto di riposo dei due transistori e verificare la saturazione di Q_2. (R: R_2 = 315588 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 = - 1.26)
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}=1321 Hz; f_{z2}=177 Hz; f_{p2}=184 Hz; $f_{z3}=f_{p3}$; f_{z4}=0 Hz; f_{p4}=9 Hz;)

Esercizio B

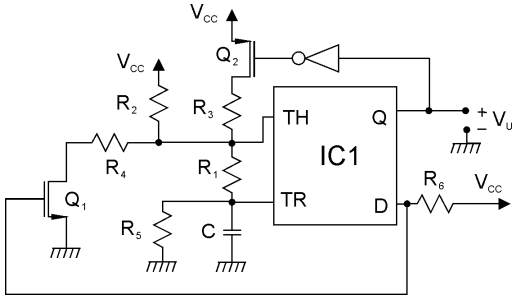
Progettare una porta logica in tecnologia CMOS, utilizzando la tecnica della pull-up network e della pull-down network, che implementi la funzione logica:

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

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

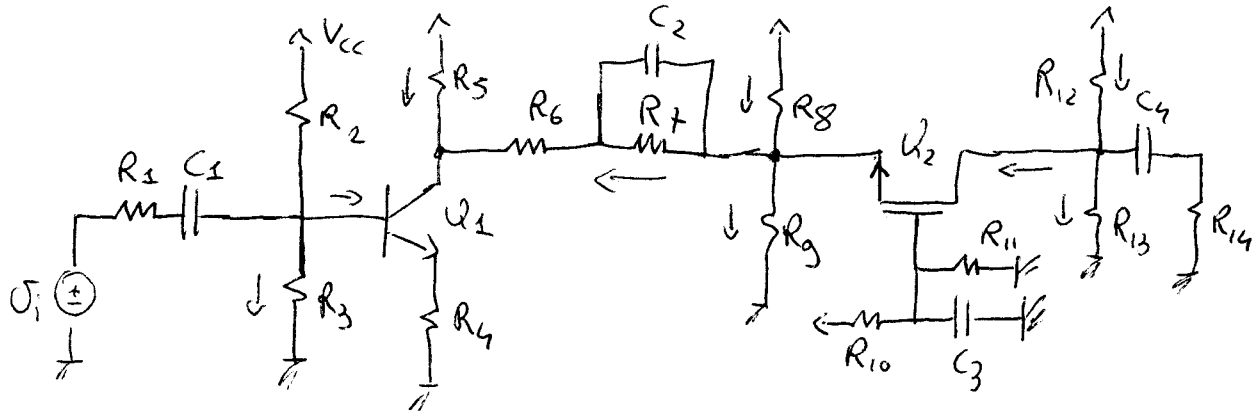
R_1 =200 Ω	R_5 = 4.8 kΩ
R_2 = 15 kΩ	R_6 = 1 kΩ
R_3 = 1 kΩ	C = 47 nF
R_4 = 9 kΩ	V_{CC} = 6 V



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; l'inverter è ideale. Determinare la frequenza del segnale di uscita del multivibratore in figura. R: f = 3547 Hz)

APPELLO 20/02/2017

ESERCIZIO A



$R_1 = 100\,\Omega$
$R_3 = 80K\Omega$
$R_4 = 125\,\Omega$
$R_5 = 21K\Omega$
$R_6 = 100\,\Omega$
$R_T = 900\,\Omega$
$R_8 = 18\,K\Omega$
$R_9 = 9\,K\Omega$
$R_{10} = 30K\Omega$
$R_{11} = 60K\Omega$
$R_{12} = 2K\Omega$
$R_{13} = 26K\Omega$
$R_{14} = 50K\Omega$
$C_1 = 2.2\,nF$
$C_2 = 1\,\mu F$
$C_3 = 1\,\mu F$
$C_4 = 330\,nF$
$V_{cc} = 18\,V$
$K = 0.5\,\frac{mA}{V^2}$

1) Det. R_2 per $V_D = 13\,V$

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

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

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

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

$$(V_{GS} - V_T) = \pm\sqrt{\frac{I_D}{K}} = 2V$$

$$V_{GS} = V_T + 2 = 3\,V$$

$$V_G = V_{cc}\,\frac{R_{11}}{R_{11}+R_{10}} = 12\,V$$

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

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

$$V_{DS} = V_D - V_S = 13 - 9 = 4\,V > (V_{GS} - V_T) = 2V \Rightarrow \text{hp verificata}$$

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

$$I_8 = \frac{V_{cc} - V_S}{R_8} = 0.5\,mA$$

$$I_9 = \frac{V_S}{R_9} = 1\,mA$$

$$I_{T6} = I_D + I_8 - I_9 = 1.5\,mA$$

$$V_C = V_{S2} - I_{T6}(R_6 + R_T) = 7.5\,V$$

$$I_5 = \frac{V_{cc} - V_C}{R_5} = 0.5\,mA$$

$I_C = I_5 + I_{67} = 2\,mA$

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

$V_E = R_4 I_C = 2.5\,V$

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

Q_1: $I_C = 2\,mA$, $V_{CE} = 5\,V$, $I_B = 6.8965\,\mu A$, $h_{FE} = 290$, $h_{ie} = 4800\,\Omega$, $h_{fe} = 300$

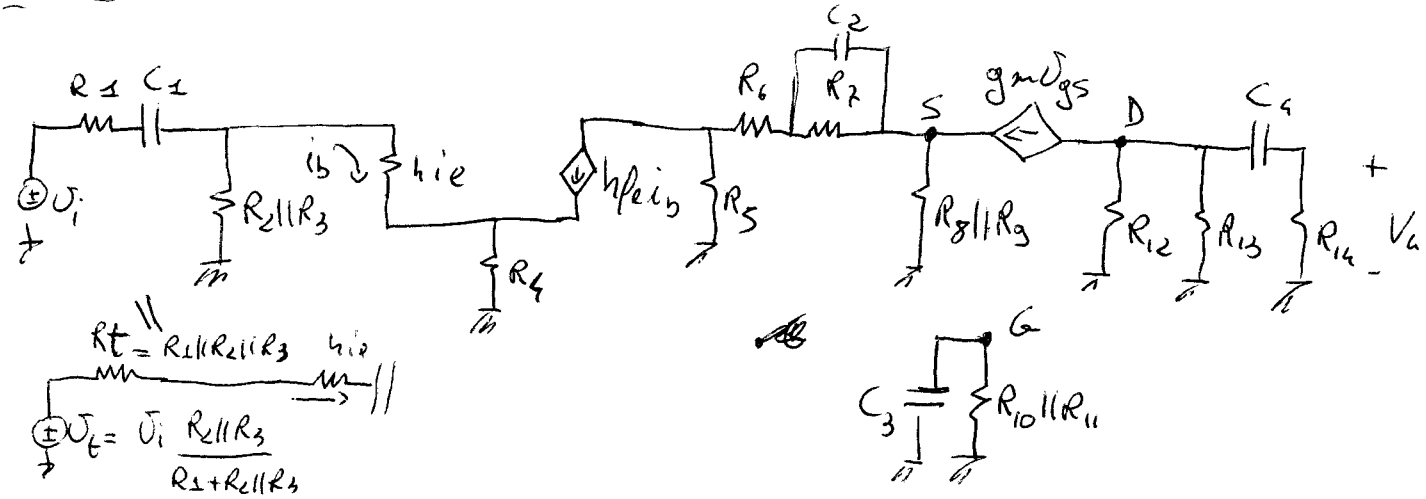
$\Rightarrow h_{FE} = 290 \Rightarrow I_B = \frac{I_C}{h_{FE}} = 6.8965\,\mu A << I_C \Rightarrow$ hp verified

$V_B = V_E + V_\gamma = 2.5 + 0.7 = 3.2\,V$

$I_3 = \frac{V_B}{R_3} = 40\,\mu A$

$I_2 = I_3 + I_B = 46.8965\,\mu A$

$R_2 = \frac{V_{cc} - V_B}{I_2} = 315588.24\,\Omega$



$V_u = (-g_m V_{gs})(R_{12} \| R_{13} \| R_{14}) = \left.\begin{matrix} \\ \\ \end{matrix}\right\} \Rightarrow V_u = g_m V_s (R_{12} \| R_{13} \| R_{14})$

$V_g = 0$

$V_s = (-h_{fe}\, i_b) \dfrac{R_5}{R_5 + R_6 + \left(R_8 \| R_9 \| \frac{1}{g_m}\right)} \left(R_8 \| R_9 \| \frac{1}{g_m}\right)$

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

2×10⁻³ 1230.63 300 0.974 461.54 0.998 2.623×10⁻⁶

$$A_{cg} = \frac{V_u}{V_i} = g_m\left(R_{12}\|R_{13}\|R_{14}\right)(-h_{fe})\frac{R_5}{R_5+R_6+\left(R_8\|R_9\|\frac{1}{g_m}\right)}\left(R_8\|R_9\|\frac{1}{g_m}\right)\frac{R_2\|R_3}{R_1+R_2\|R_3}\frac{1}{\left(R_1\|R_2\|R_3\right)+h_{ie}+R_4(h_{fe}+1)}$$

$$= -1.264 \quad (|A_{cg}| = 2\,dB)$$

POLI E ZERI

C_1: $f_{z1} = 0$ Hz

$$f_{p1} = \frac{1}{2\pi C_2 R_{v1}} = 1320.9 \text{ Hz}$$

$$R_{v1} = R_1 + R_2\|R_3\|\left[h_{ie} + R_4(h_{fe}+1)\right] = 54265.68\ \Omega$$

C_2: $f_{z2} = \frac{1}{2\pi C_2 R_7} = 176.84$ Hz

$$f_{p2} = \frac{1}{2\pi C_2 R_{v2}} = 184.22 \text{ Hz}$$

$$R_{v2} = R_7\|\left[R_5+R_6+\left(R_8\|R_9\|\frac{1}{g_m}\right)\right] = 863.9\ \Omega$$

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

C_4: $f_{z4} = 0$ Hz

$$f_{p4} = \frac{1}{2\pi C_4 R_{v4}} = 9.3 \text{ Hz}$$

$$R_{v4} = \left(R_{12}\|R_{13}\right) + R_{14} = 51857.1\ \Omega$$

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

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

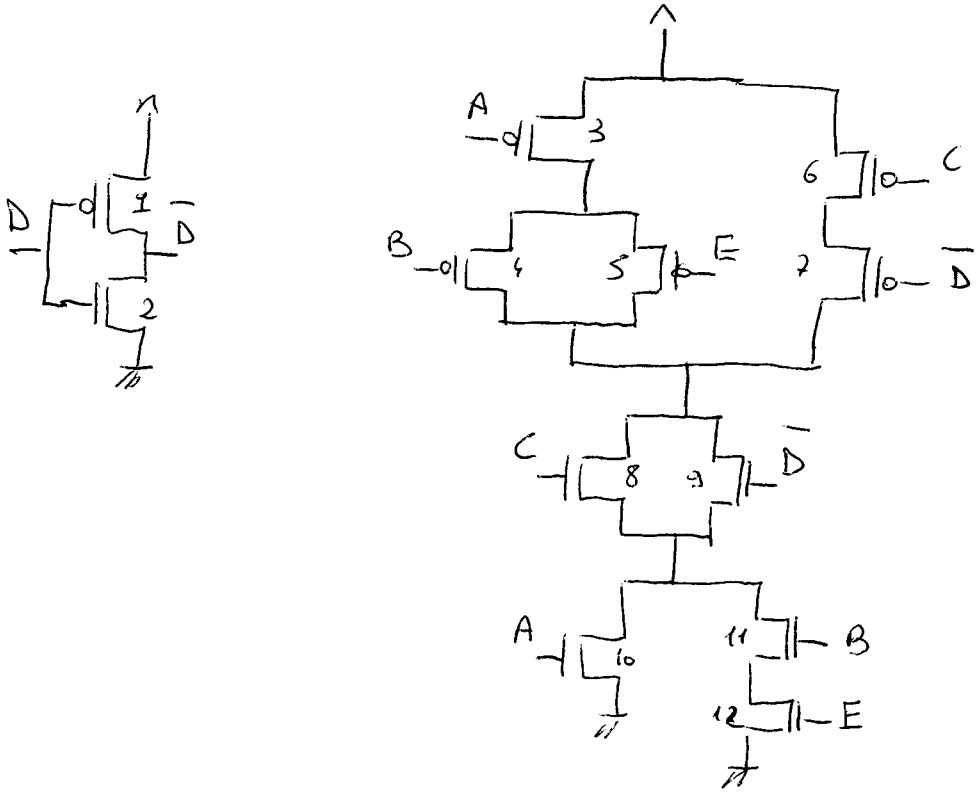
$$= \bar{A}\bar{B}C\bar{D}+\bar{A}\bar{B}D+\bar{A}\bar{B}\bar{E}+\bar{A}\bar{B}\bar{C}\bar{D}+\bar{A}B\bar{E}+\bar{C}D =$$

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

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

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

N MOS = 5×2+2 = 12 MOS



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

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

} INVERTER DI BASE

) PUN: serie Q_3-Q_4 ; Q_3-Q_5 ; Q_6-Q_7 $\quad \left(\frac{W}{L}\right)_3 = \left(\frac{W}{L}\right)_4 = x$

$$\frac{1}{x}+\frac{1}{x}=\frac{1}{p} \Rightarrow x = 2p = 10 \Rightarrow \left(\frac{W}{L}\right)_{3,4,5,6,7} = 10$$

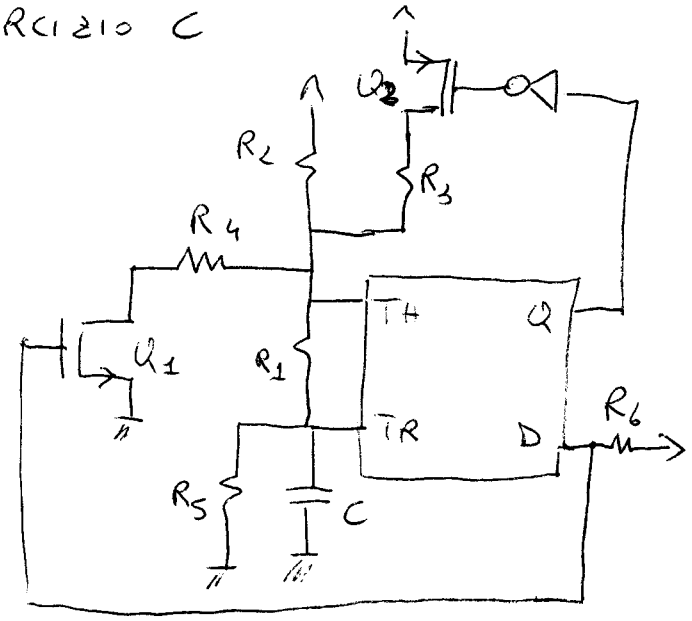
) PDN: serie Q_8-Q_{11}, Q_{12} ; Q_9-Q_{11}-Q_{12}

$$\frac{1}{x}+\frac{1}{x}+\frac{1}{x}=\frac{1}{n} \Rightarrow x = 3n = 6 = \left(\frac{W}{L}\right)_{8,9,11,12}$$

serie Q_8-Q_{10} ; Q_9-Q_{10}

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

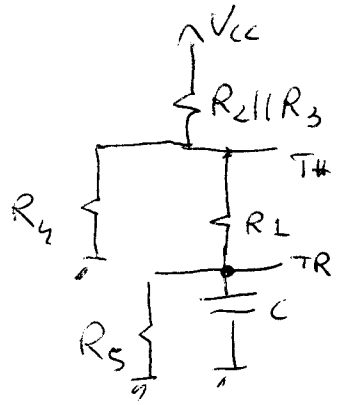
EJERCICIO C



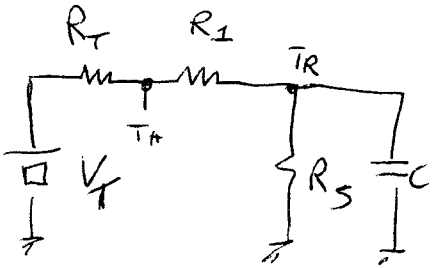
$R_1 = 200\,\Omega$
$R_2 = 15\,K\Omega$
$R_3 = 1\,K\Omega$
$R_4 = 9\,K\Omega$
$R_5 = 4800\,\Omega$
$R_6 = 1\,K\Omega$
$C = 47\,nF$

1) $Q = 1 \Rightarrow V_{G2} = 0\,V \quad V_{S2} = V_{CC} \Rightarrow V_{GS2} = -V_{CC} \Rightarrow Q_2$ ON

$D = HI \Rightarrow V_{G1} = V_{CC} \quad V_{S1} = 0\,V \Rightarrow V_{GS1} = V_{CC} \Rightarrow Q_1$ ON



$\Rightarrow$



$$V_T = \frac{V_{CC}\,R_4}{R_2 \| R_3 + R_4} = 5.434\,V$$

$$R_T = R_2 \| R_3 \| R_4 = 843.06\,\Omega$$

$$V_{i\,I} = \frac{1}{3} V_{CC} = 2\,V$$

$$V_f = V_T \frac{1}{R_T + R_1 + R_5} \cdot R_5 = 4.459\,4\,V$$

$$I_{2\|3} = \frac{V_{CC} - V_{TH}}{R_2 \| R_3} = \frac{2}{337.5} = 2.1\bar{3}\,mA$$

$$I_4 = \frac{V_{TH}}{R_4} = \frac{2}{9 \times 10^3} = 4.\bar{4} \times 10^{-4}\,A$$

$$I_1 = I_{2\|3} - I_4 = 1.68\bar{8}\,mA$$

$$V_{con} = V_{TH} - R_1 I_1 = 3.66\bar{2}\,V$$

$V_i < V_{con} < V_f$

$2 < 3.66\bar{2} < 4.459\,4$

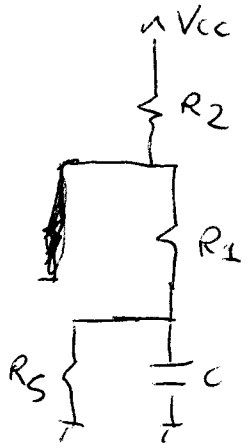
$$R_{V_1} = R_5 \| [R_1 + R_T] = 860.9\,\Omega$$

$$\tau_1 = R_{V_1} C = 40.46\,\mu s$$

$$T_1 = \tau_1 \ln\left(\frac{V_{i1} - V_{f1}}{V_{com1} - V_{f1}}\right) = 45.58\,\mu s$$

2) $Q = 0$ $\Rightarrow Q_2$ OFF

$D = \phi$ $\Rightarrow Q_1$ OFF



$$V_{i2} = V_{com1} = 3.662\ V$$

$$V_{com2} = V_{i1} = 2V$$

$$V_{f2} = V_{cc}\frac{R_5}{R_1 + R_2 + R_5} = 1.44\ V$$

$$V_{i2} > V_{com2} > V_{f2}$$

$$3.66V > 2V > 1.44V$$

$$R_{V2} = R_5 \,||\, (R_1 + R_2) = 3648\,\Omega$$

$$\tau_2 = C R_{V2} = 171.456\,\mu s$$

$$T_2 = \tau_2 \ln\left(\frac{V_{i2} - V_{f2}}{V_{com2} - V_{f2}}\right) = 2.363 \times 10^{-4}\ s$$

$$T = T_1 + T_2 = 2.819 \times 10^{-4}\ s$$

$$f = \frac{1}{T} = 3547.27\ Hz$$