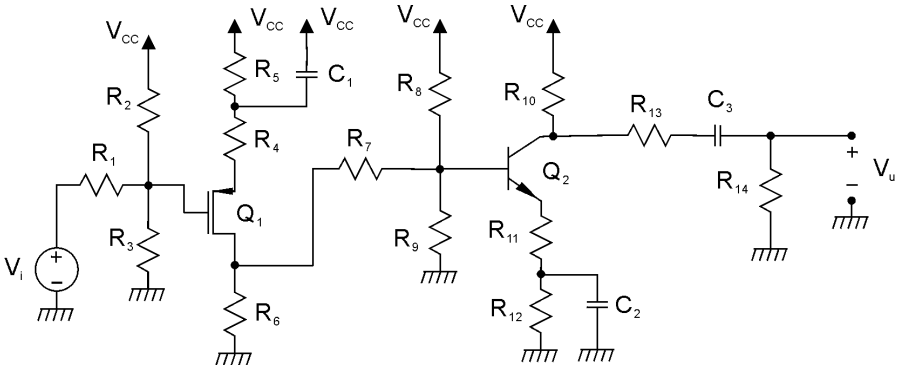
ELETTRONICA DIGITALE

Corso di Laurea in Ingegneria Informatica

Prova scritta del 08 giugno 2017

Esercizio A

R_1 = 20 kΩ	R_{11} = 500 Ω
R_2 = 10 kΩ	R_{12} = 2.5 kΩ
R_3 = 20 kΩ	R_{13} = 1 kΩ
R_4 = 500 Ω	R_{14} = 15 kΩ
R_6 = 15 kΩ	C_1 = 1 μF
R_7 = 500 Ω	C_2 = 47 nF
R_8 = 56.5 kΩ	C_3= 330 pF
R_9 = 6.7 kΩ	V_{CC} = 18 V
R_{10} = 3.5 kΩ	



Q_1 è un transistore MOS a canale p 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_5 in modo che, in condizioni di riposo, la tensione sul collettore di Q_2 sia 11 V. Determinare, inoltre, il punto di riposo dei due transistori e verificare la saturazione di Q_1. (R: R_5 = 4500 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 = 4.7)
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}=35 Hz; f_{p1}=177 Hz; f_{z2}=1354 Hz; f_{p2}=7740 Hz; f_{z3}= 0 Hz; f_{p3}=24733 Hz)

Esercizio B

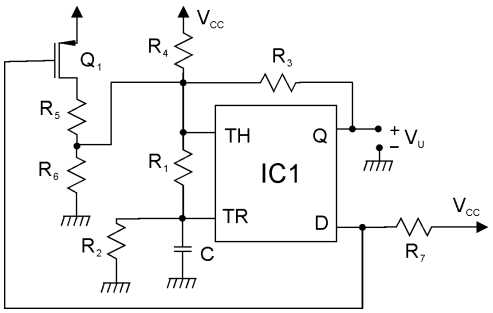
Progettare una porta logica in tecnologia CMOS, utilizzando la tecnica della pull-up network e della pull-down network, che implementi la funzione logica:

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

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.

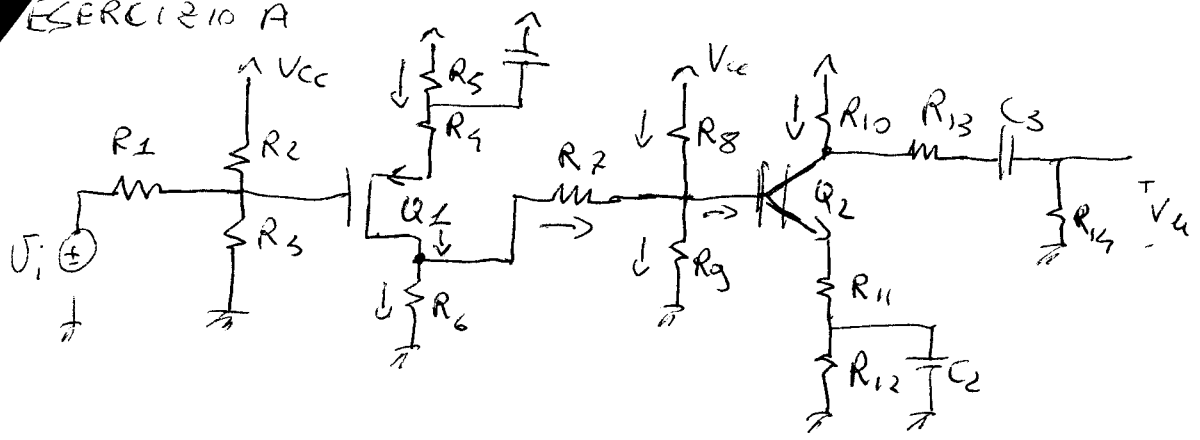
Esercizio C

R_1 =50 Ω	R_6 = 10 kΩ
R_2 = 4 kΩ	R_7 = 1 kΩ
R_3 = 200 Ω	C = 33 nF
R_4 = 1 kΩ	V_{CC} = 6 V
R_5 = 1 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. Determinare la frequenza del segnale di uscita del multivibratore in figura. (R: f = 79226 Hz)

ESERCIZIO A



$R_1 = 20\,k\Omega$
$R_2 = 10\,k\Omega$
$R_3 = 20\,k\Omega$
$R_4 = 500\,\Omega$
$R_6 = 15\,k\Omega$
$R_7 = 500\,\Omega$
$R_8 = 56.5\,k\Omega$
$R_9 = 6.7\,k\Omega$
$R_{10} = 3.5\,k\Omega$
$R_{11} = 500\,\Omega$
$R_{12} = 2.5\,k\Omega$
$R_{13} = 1\,k\Omega$
$R_{14} = 15\,k\Omega$
$C_1 = 1\,\mu F$
$C_2 = 47\,nF$
$C_3 = 33\,pF$
$V_{cc} = 18\,V$
$K = 0.5\ \frac{mA}{V^2}$
$V_T = -1\,V$

1) Det. R_5 per $V_C = 11\,V$

$$I_{10} = \frac{V_{cc} - V_C}{R_{10}} = 2\,mA$$

hp: $I_B \ll I_C \Rightarrow I_E \simeq I_C = 2\,mA$

$$V_E = I_E (R_{11} + R_{12}) = 6\,V$$

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

$\Rightarrow$ Siamo nel punto di lavoro $V_{CE} = 5\,V$ $I_C = 2\,mA$

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

$$I_B = \frac{I_C}{h_{FE}} = 6.8965\,\mu A \ll I_C \Rightarrow \underline{\text{hp. ok}}$$

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

$$I_8 = \frac{V_{cc} - V_B}{R_8} = 0.2\,mA$$

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

$$I_1 = I_9 + I_B - I_8 = 0.806896\,mA$$

$$V_D = V_B + R_7 I_1 = 7.103\,V$$

$$I_6 = \frac{V_D}{R_6} = 0.47356\,mA$$

$$I_D = I_6 + I_1 = 1.28\,mA$$

hp: Q_1 saturo $\Rightarrow I_D = k(V_{GS} - V_T)^2$

$$V_{GS} = V_T - \sqrt{\frac{I_D}{K}} = -2.6\,V$$

$$Q_2 \equiv \begin{cases} I_C = 2\,mA \\ V_{CE} = 5\,V \\ h_{FE} = 290 \\ h_{ie} = 4800\,\Omega \\ h_{fe} = 300 \end{cases}$$

$$g_m = 2k\,|V_{GS} - V_T| = 1.6 \times 10^{-3}\ A/V$$

$$G = V_{cc}\,\frac{R_1 \| R_3}{R_2 + R_1 \| R_3} = 9\,V$$

$$V_S = V_G - V_{GS} = 9 + 2.6 = 11.6\,V$$

$$V_{DS} = V_D - V_S = 7.103 - 11.6 = -4.497\,V \quad < \quad V_{GS} - V_T = -1.6\,V$$

$$\text{hp} \Rightarrow \text{OK}$$

$$I_S = I_D = \frac{V_{cc} - V_S}{R_4 + R_5}$$

$$\Rightarrow R_4 + R_5 = \frac{V_{cc} - V_S}{I_D} = 5000\,\Omega$$

$$\Rightarrow R_5 = 5000 - 500 = 4500\,\Omega$$

$$Q_1 = \begin{cases} I_{SD} = 1.28\,mA \\ V_{DS} = -4.497\,V \\ V_{GS} = -2.6\,V \\ g_m = 1.6 \times 10^{-3}\,\frac{A}{V} \end{cases}$$

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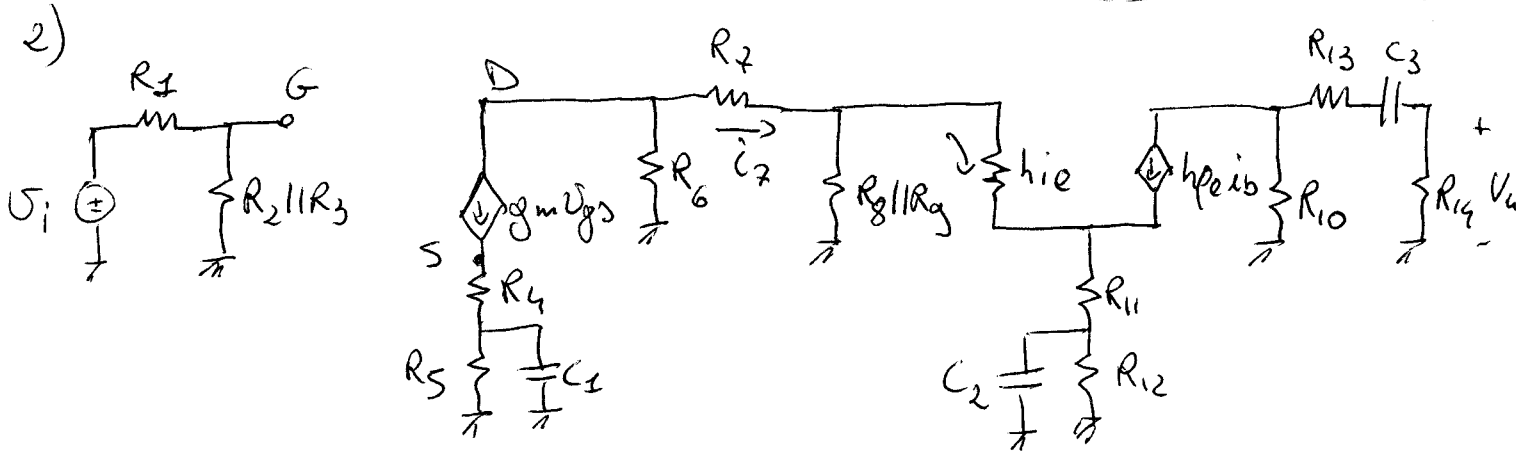
2)



$$V_u = (-h_{fe}\, i_b)\,\frac{R_{10}}{R_{10} + R_{13} + R_{14}} \cdot R_{14}$$

$$i_b = i_7\,\frac{R_8 \| R_g}{(R_8 \| R_g) + h_{ie} + R_{11}(h_{fe} + 1)}$$

$$i_7 = (-g_m V_{gs})\,\frac{R_6}{R_6 + R_7 + R_8 \| R_g \| [h_{ie} + R_{11}(h_{fe} + 1)]}$$

$$V_S = (g_m V_{gs})\, R_4$$

$$V_{gs} = V_g - V_S = V_g - g_m V_{gs} R_4 = \frac{V_g}{1 + g_m R_4}$$

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

$$\frac{V_u}{V_i} = (-h_{fe}) \frac{R_{10} R_{14}}{R_{10} + R_{13} + R_{14}} \cdot \frac{R_8 \| R_9}{R_8 \| R_9 + h_{ie} + R_{11}(h_{fe}+1)} (-g_m) \frac{R_6}{R_6 + R_7 + R_8 \| R_9 \| [h_{ie} + R_{11}(h_{fe}+$$

$$\cdot \frac{1}{1 + g_m R_4} \cdot \frac{R_2 \| R_3}{R_1 + R_2 \| R_3} = 4.70 \ \Omega$$

$$|A_{CB}|_{dB} = 13.44$$

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3) POLI E ZERI

C_1: $f_{z1} = \frac{1}{2\pi R_5 C_1} = 35.37$ Hz

$f_{p1} = \frac{1}{2\pi R_{V1} C_1} = 176.84$ Hz

$R_{V1} = R_5 \| \left[R_4 + \frac{1}{g_m} \right] = 900 \ \Omega$

C_2: $f_{z2} = \frac{1}{2\pi C_2 R_{12}} = 1354.51$ Hz

$f_{p2} = \frac{1}{2\pi C_2 R_{V2}} = 7740.1$ Hz

$R_{V2} = R_{12} \| \left\{ R_{11} + \frac{[(R_6+R_7) \| R_8 \| R_9] + h_{ie}}{(h_{fe}+1)} \right\} = 437.5 \ \Omega$

C_3: $f_{z3} = \phi$ Hz

$f_{p3} = \frac{1}{2\pi C_3 R_{V3}} = 24732.7$ Hz

$R_{V3} = R_{10} + R_{13} + R_{14} = 19500 \ \Omega$

ESERCIZIO B

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

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

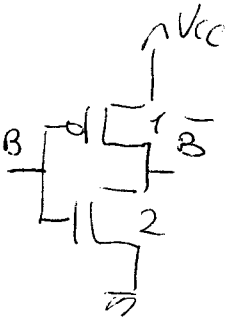
$$= \bar{A}\,\underset{\times}{\bar{C}}\,\bar{D} + B\,\bar{C}\,\bar{D} + \bar{C}\,\underset{0}{\bar{D}}\,\bar{E} + \bar{A}\,\underset{\times}{C}\,\bar{D} + C\,\underset{0}{\bar{D}}\,\bar{E} =$$

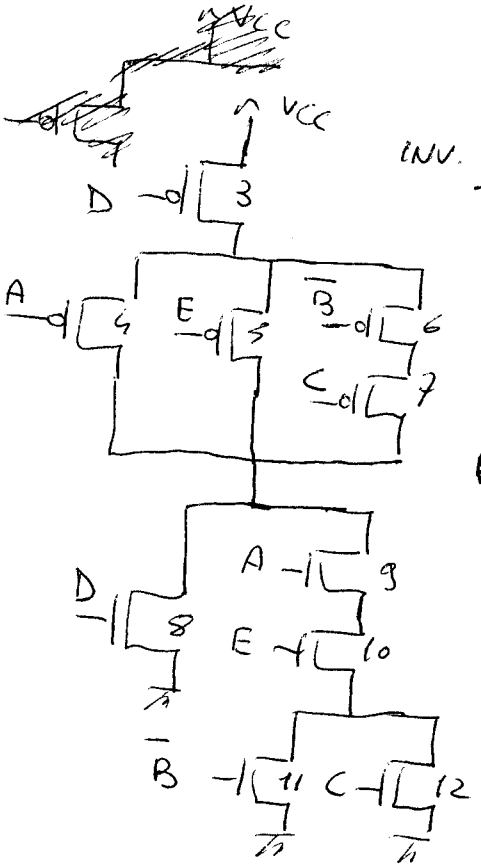
$$= \bar{A}\,\bar{D}(\bar{C}+C) + \bar{D}\,\bar{E}(\bar{C}+C) + B\,\bar{C}\,\bar{D} =$$

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

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

N. MOS = 5 x 2 + 2 = 12 MOS





INV. $\left(\frac{W}{L}\right)_1 = p = 5$ — INVERTER Q1

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

PUN $\left(\frac{W}{L}\right)_{3,6,7} = 3p = 15$

$\left(\frac{W}{L}\right)_{4,5} = 1.5p = 7.5$

PDN $\left(\frac{W}{L}\right)_{9,10,11,12} = 3n = 6$

$\left(\frac{W}{L}\right)_8 = n = 2$

) PUN

-) SERIE $Q_3 - Q_6 - Q_7$

$$\frac{1}{X} + \frac{1}{X} + \frac{1}{X} = \frac{1}{P} \Rightarrow X = 3p = 15$$

-) SERIE $Q_3 Q_4$ oppure $Q_3 - Q_5$

$$\frac{1}{X} + \frac{1}{3p} = \frac{1}{P} \Rightarrow X = 1.5p = 7.5$$

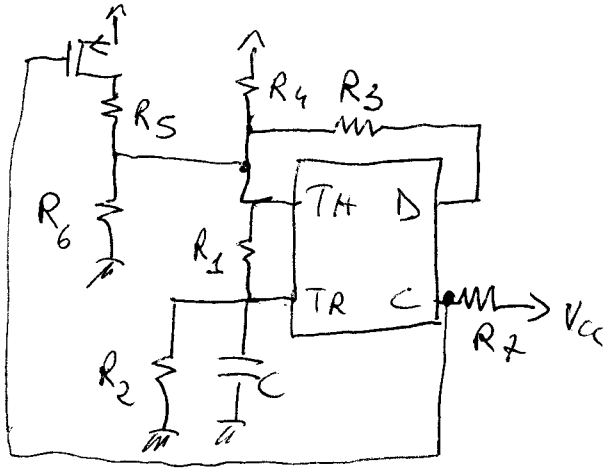
PDN

-) SERIE $Q_9 - Q_{10} - Q_{11}$ oppure $Q_9 - Q_{10} - Q_{12}$

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

-) Q_8 DA SOLO $\Rightarrow X = n = 2$

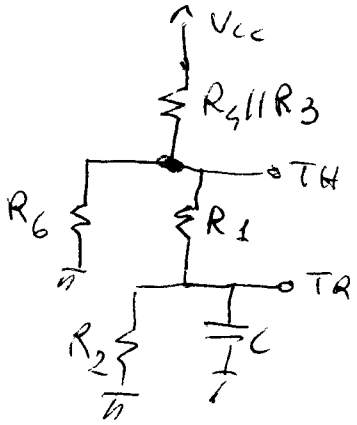
ESERCIZIO C



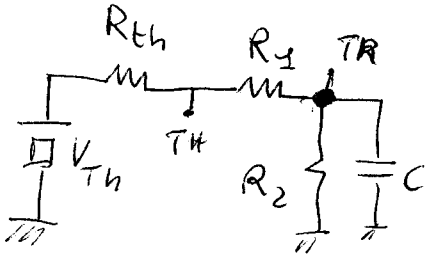
$R_1 = 50\,\Omega$
$R_2 = 4\,K\Omega$
$R_3 = 200\,\Omega$
$R_4 = 1\,k\Omega$
$R_5 = 1\,k\Omega$
$R_6 = 10\,k\Omega$
$R_7 = 1\,k\Omega$
$C = 33\,nF$
$V_{cc} = 6\,V$

1) $Q = 1$

$D = HI \Rightarrow V_{G1} = V_{cc}$ $V_{S1} = V_{cc}$ $V_{GS1} = 0\,V > V_T = -1\,V \Rightarrow Q_2$ OFF



$\Rightarrow$



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

$V_{Th} = \frac{V_{cc} R_6}{R_6 + R_3 \| R_4} = 5.9$

$R_{Th} = R_3 \| R_4 \| R_6 = 163.93\,\Omega$

$V_f = V_{Th} \frac{R_2}{R_{Th} + R_1 + R_2} = 5.602\,V$

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

$I_1 = \frac{V_{Th} - V_{TH}}{R_{th}} = 11.6\,mA$ $V_{COR} = V_{TH} - R_1 I_{R_1} = 3.42\,V$

$V_i < V_{COR} < V_f$
$2 < 3.42 < 5.602$

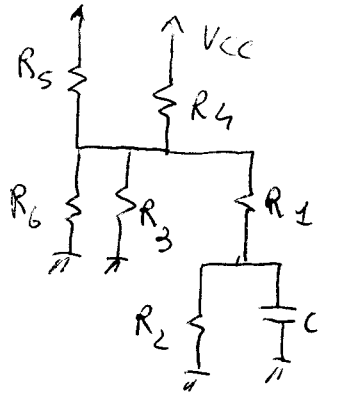
$R_{V1} = R_2 \| (R_1 + R_{Th}) = R_2 \| (R_1 + R_3 \| R_4 \| R_6) = 203.073\,\Omega$

$\tau_1 = R_{V1} C_1 = 6.704\,\mu s$

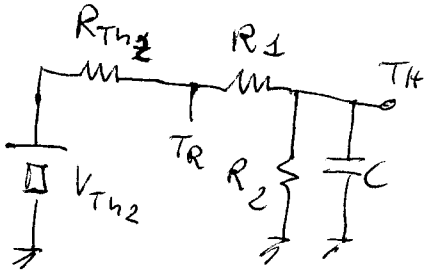
$T_1 = \tau_1 \ln\left(\frac{V_{i_1} - V_{f_1}}{V_{COR_1} - V_{f_1}}\right) = 3.359\,\mu s$

$Q=0$

$D=0 \Rightarrow V_{G1}=0\,V \quad V_{S1}=V_{CC} \Rightarrow V_{GS1}=-6\,V < V_T=-1\,V \Rightarrow Q_2$ ON



$\Rightarrow$



$$V_{Th2}=V_{CC}\frac{R_3\|R_6}{(R_3\|R_6)+(R_5\|R_4)}=1.69\,V$$

$$R_{Th2}=R_3\|R_6\|R_4\|R_5=140.845\,\Omega$$

$$V_{f2}=V_{Th2}\frac{R_2}{R_{Th2}+R_1+R_2}=1.613\,V$$

$V_{i2}=V_{con1}=3.42\,V$

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

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

$3.42 > 2 > 1.613$

$$R_{V2}=R_2\|[R_1+R_{Th2}]=R_2\|[R_1+R_3\|R_6\|R_4\|R_5]=182.15\,\Omega$$

$$\tau_2=R_{V2}\cdot C=6.011\,\mu s$$

$$T_2=\tau_2\ln\left(\frac{V_{i2}-V_{f2}}{V_{con2}-V_{f2}}\right)=9.263\,\mu s$$

$$T=T_1+T_2=12.622\,\mu s$$

$$f=\frac{1}{T}=79.226.23\,Hz$$