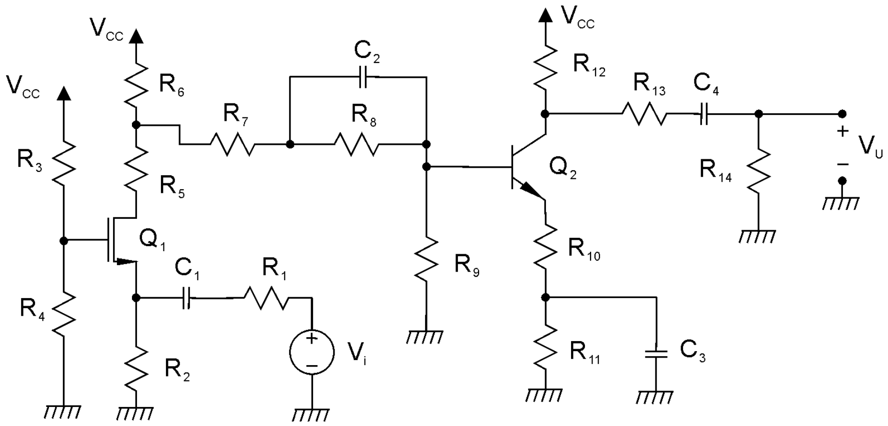
ELETTRONICA DIGITALE

Corso di Laurea in Ingegneria Informatica

Prova scritta del 19 luglio 2018

Esercizio A

$R_1 = 50\ \Omega$	$R_9 = 11.4\ k\Omega$
$R_3 = 50\ k\Omega$	$R_{10} = 400\ \Omega$
$R_4 = 40\ k\Omega$	$R_{11} = 2.1\ k\Omega$
$R_5 = 1\ k\Omega$	$R_{12} = 4\ k\Omega$
$R_6 = 2\ k\Omega$	$R_{13} = 100\ \Omega$
$R_7 = 500\ \Omega$	$R_{14} = 10\ k\Omega$
$R_8 = 12\ k\Omega$	$V_{CC} = 18$ V



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_2 in modo che, in condizioni di riposo, la tensione sul collettore di Q_2 sia 10 V. Determinare, inoltre, il punto di riposo dei due transistori e verificare la saturazione di Q_1. (R: R_2 = 1929.35 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 = -21.46)

Esercizio B

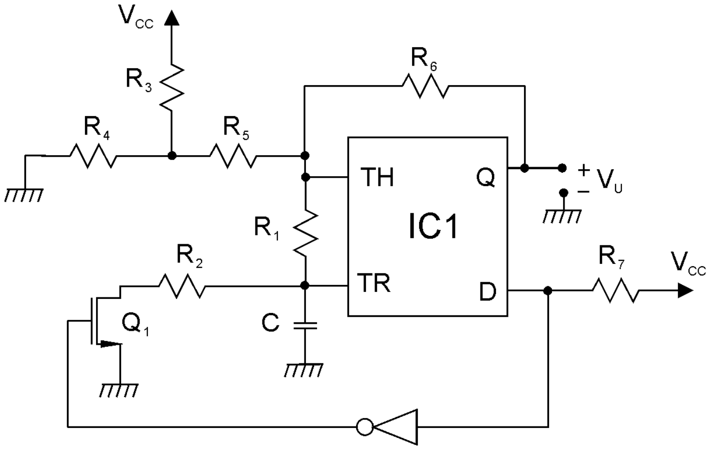
Progettare una porta logica in tecnologia CMOS, utilizzando la tecnica della pull-up network e della pull-down network, che implementi la funzione logica:

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

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. (R: N = 18)

Esercizio C

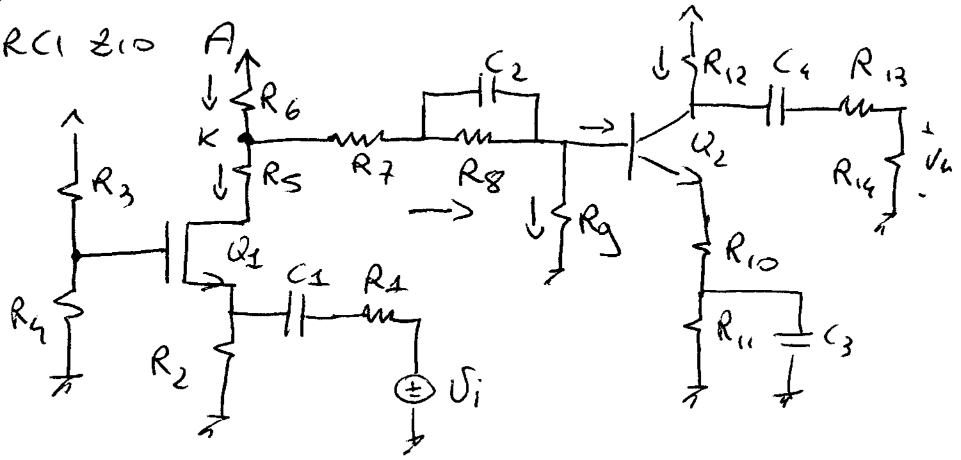
$R_1 = 400\ \Omega$	$R_6 = 500\ \Omega$
$R_2 = 200\ \Omega$	$R_7 = 1\ k\Omega$
$R_3 = 3\ k\Omega$	C = 820 nF
$R_4 = 1\ K\Omega$	$\mathbf{V_{CC} = 6\ V}$
$R_5 = 250\ \Omega$	



Il circuito IC_1 è un NE555 alimentato a $\mathbf{V_{CC} = 6V}$, Q_1 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 = 1769.84 Hz)

APPELLO 19/07/18

ESERCIZIO A



$R_1 = 50\,\Omega$
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$R_6 = 2\,k\Omega$
$R_7 = 500\,\Omega$
$R_8 = 12\,k\Omega$
$R_9 = 11.4\,k\Omega$
$R_{10} = 400\,\Omega$
$R_{11} = 2.1\,k\Omega$
$R_{12} = 4\,k\Omega$
$R_{13} = 800\,\Omega$
$R_{14} = 10\,k\Omega$
$V_{cc} = 18\,V$
$k = 0.5\,mA/V^2$

1) CALCOLARE R_2 per $V_C = 10V$

$$I_{12} = \frac{V_{cc} - V_c}{R_{12}} = 2mA = I_c$$

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

$$V_E = (R_{10} + R_{11}) I_E = 5V$$

$$V_{CE} = V_C - V_E = 10 - 5 = 5V$$

$$I_B = \frac{I_C}{h_{FE}} = 6.8965\,\mu A \quad << I_C \Rightarrow \text{hp ok}$$

$$V_B = V_E + V_\gamma = 5.7V$$

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

$$I_8 = I_9 + I_B = 5.068965 \times 10^{-4}\,A$$

$$V_K = V_B + (R_7 + R_8) I_8 = 12.0362\,V$$

$$I_6 = \frac{V_{cc} - V_K}{R_6} = 2.9819\,mA$$

$$I_5 = I_6 - I_8 = 2.475\,mA \simeq I_D$$

$$I_G = \emptyset \Rightarrow I_S = I_D = 2.475\,mA$$

$$V_G = V_{cc} \frac{R_4}{R_3 + R_4} = 8V$$

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

$$V_{GS} = V_T \underset{NMOS}{\oplus} \sqrt{\frac{I_D}{k}} = 3.22486\,V$$

$$V_S = V_G - V_{GS} = 4.77514\,V$$

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

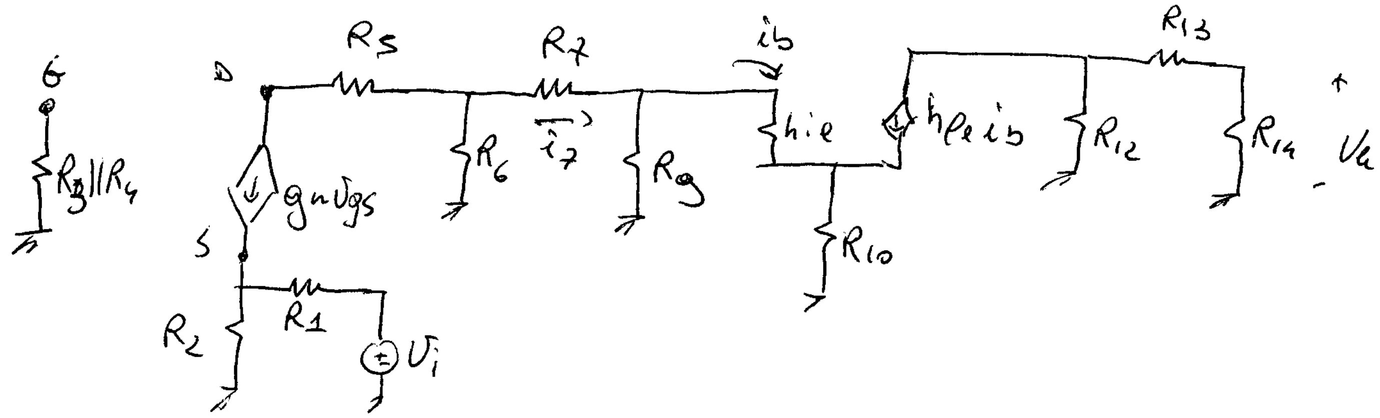
$$Q_1: \begin{cases} I_D = 2.475\,mA \\ V_{DS} = 4.786\,V \\ V_{GS} = 3.225\,V \\ g_m = 2.225 \times 10^{-3}\,\frac{A}{V} \end{cases}$$

$$= \frac{V_S}{I_S} = \frac{4.77514}{2.475 \times 10^{-3}} = \underline{\underline{1929.35\ \Omega}}$$

$$\cancel{V_{DS}} \quad V_D = V_K - R_5 I_D = 9.5612\,V$$

$$V_{DS} = V_D - V_S = 4.78606\,V > V_{GS} - V_T = 2.22486\,V \Rightarrow h_p \text{ OK}$$

$$g_m = 2K(V_{GS} - V_T) = 2.22486 \times 10^{-3}\ \frac{A}{V}$$



$$V_u = (-h_{fe} i_b) \frac{R_{12}}{R_{12} + R_{13} + R_{14}} \cdot R_{14}$$

$$i_b = i_7 \frac{R_9}{R_9 + h_{ie} + R_{10}(h_{fe}+1)}$$

$$i_7 = (-g_m v_{gs}) \frac{R_6}{R_6 + R_7 + \{R_9 \| [h_{ie} + R_{10}(h_{fe}+1)]\}}$$

$$v_g = \emptyset$$

$$v_S = v_i \frac{R_2 \| \frac{1}{g_m}}{R_1 + R_2 \| \frac{1}{g_m}} = v_i \frac{\frac{R_2 \frac{1}{g_m}}{R_2 + 1/g_m}}{R_1 + \frac{R_2/g_m}{R_2 + \frac{1}{g_m}}} = v_i \frac{\frac{R_2}{1 + g_m R_2}}{R_1 + \frac{R_2}{1 + g_m R_2}} = v_i \frac{R_2}{R_1 + R_2(1 + g_m R_1)}$$

$$= v_i \frac{R_2}{R_1 + R_2 + g_m R_1 R_2}$$

Se ~~uso~~ sovrapp. effetti

$$v_S = v_i \frac{R_2}{R_1 + R_2} + g_m v_{gs} \frac{R_1 R_2}{R_1 + R_2} \Rightarrow v_S = v_i \frac{\frac{R_2}{R_1 + R_2}}{1 + g_m \frac{R_1 R_2}{R_1 + R_2}} = v_i \frac{R_2}{R_1 + R_2 + g_m R_1 R_2}$$

$$\frac{V_u}{V_i} = (-h_{fe}) \underbrace{\frac{R_{12}\, R_{14}}{R_{12}+R_{13}+R_{14}}}^{2836.88} \underbrace{\frac{R_9}{R_9+h_{ie}+R_{10}(h_{fe}+1)}}^{8.3355\times10^{-2}} \underbrace{(+g_m)}^{2.225\times10^{-3}} \underbrace{\frac{R_6}{R_6+R_7+\{R_9 \| [h_{ie}+R_{10}(h_{fe}+1)}}^{0.15445}$$

$$\cdot \underbrace{\frac{(R_2 \| 1/g_m)}{R_1+(R_2 \| \frac{1}{g_m})}}^{0.8794} = -21.46 \qquad \left|\frac{V_u}{V_i}\right| = 26.63\ dB$$

ESERCIZIO B

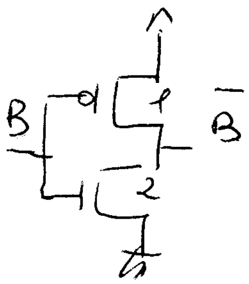
$$Y = (\overline{A+D})(\bar B + \bar C + E) + \bar A(\bar B D + DE) + \bar C(A\bar D + B\bar E) =$$

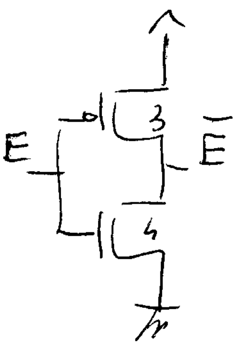
$$= \bar A \bar D(\bar B + \bar C + E) + \bar A \bar B D + \bar A DE + A\bar C \bar D + B \bar C \bar E =$$

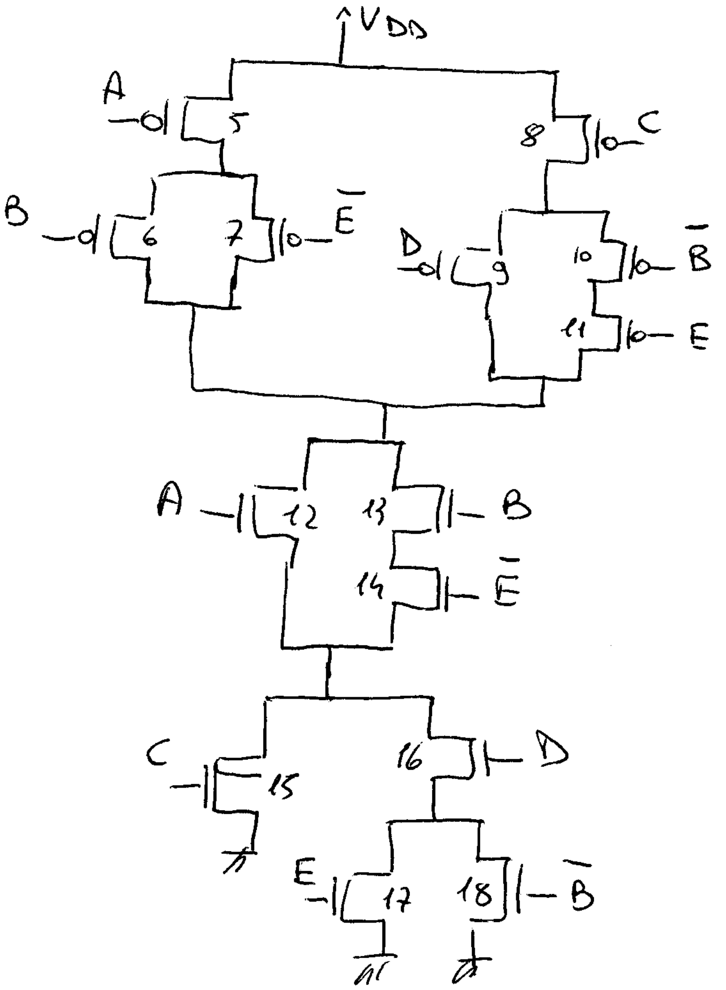
$$= \bar A \bar D \bar B + \bar A \bar D \bar C + \bar A \bar D E + \bar A \bar B D + \bar A DE + A \bar C \bar D + B \bar C \bar E =$$

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

$$= \bar A(\bar B + E) + \bar C(\bar D + B\bar E) \qquad \#\ MOS: 7\times 2 + 2\times 2 = 18$$







INVERTER

$$\left(\frac{W}{L}\right)_{1,3} = p = 5$$

$$\left(\frac{W}{L}\right)_{2,4} = n = 2$$

INVERTER DI BASE

·) PUN

-) WORST CASE 3 ROS :

$Q_8 - Q_{10} - Q_{11}$: $\frac{1}{x} + \frac{1}{x} + \frac{1}{x} = \frac{1}{p} \Rightarrow x = 3p = 15$

$$\left(\frac{W}{L}\right)_{8,10,11} = 15$$

-) WORST CASE 2 ROS

$Q_8 - Q_9$ (Q_8 già dim) : $\frac{1}{x} + \frac{1}{3p} = \frac{1}{p} \Rightarrow x = \frac{3}{2} p = 7.5$

$$\left(\frac{W}{L}\right)_9 = 7.5$$

$Q_5 - Q_7$ oppure $Q_5 - Q_6$: $\frac{1}{x} + \frac{1}{x} = \frac{1}{p} \Rightarrow x = 2p = 10$

$$\left(\frac{W}{L}\right)_{5,6,7} = 10$$

·) PDN

-) WORST CASE 4 ROS

$Q_{13} - Q_{14} - Q_{16} - Q_{17}$: NON POSSIBILE PER $E - \overline{E}$

$Q_{13} - Q_{14} - Q_{16} - Q_{18}$: " " " $B - \overline{B}$

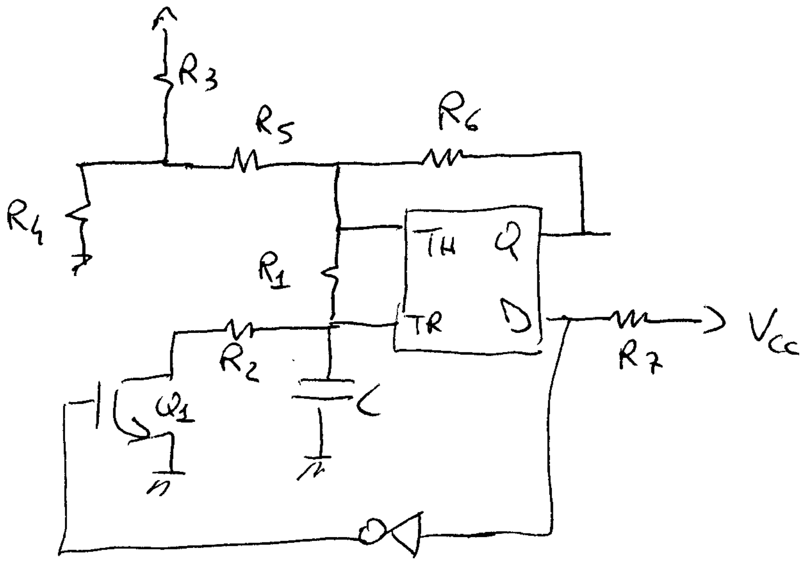
-) WORST CASE 3 ROS

$Q_{13} - Q_{14} - Q_{15}$; $Q_{12} - Q_{16} - Q_{17}$; $Q_{12} - Q_{16} - Q_{18}$

$\frac{1}{y} + \frac{1}{y} + \frac{1}{y} = \frac{1}{n} \Rightarrow$ ~~...~~ $y = 3n = 6$

$$\left(\frac{W}{L}\right)_{12,13,14,15,16,17,18} = 6$$

ESERCIZIO C



$R_1 = 400\ \Omega$

$R_2 = 200\ \Omega$

$R_3 = 3\ k\Omega$

$R_4 = 1\ k\Omega$

$R_5 = 250\ \Omega$

$R_6 = 500\ \Omega$

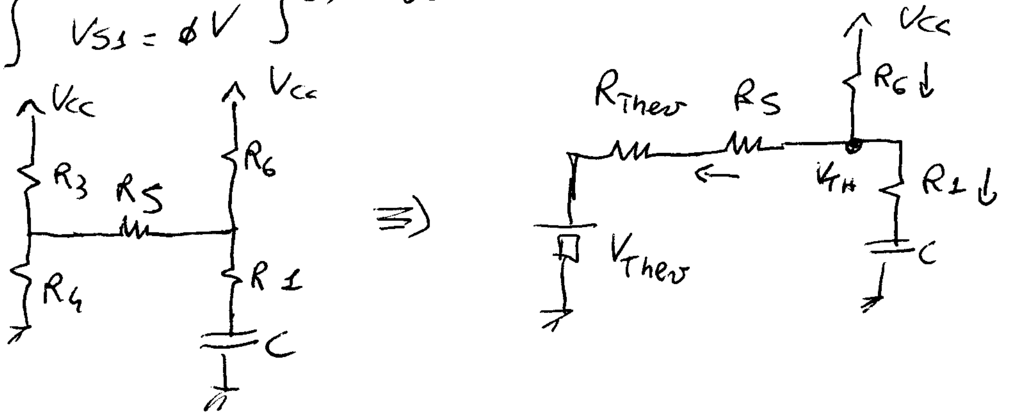
$R_7 = 1\ k\Omega$

$C = 820\ nF$

$V_{cc} = 6\ V$

1° CASO

$$\left.\begin{array}{l} Q = 1 \\ D = HI \end{array}\right\} \left.\begin{array}{l} V_{G1} = \phi\ V \\ V_{S1} = \phi\ V \end{array}\right\} \Rightarrow V_{GS1} = \phi V \Rightarrow Q_1 \text{ OFF}$$



$$V_{Thev} = \frac{V_{cc} R_4}{R_3 + R_4} = 1.5\ V$$

$$R_{Thev} = R_3 \| R_4 = 750\ \Omega$$

$$\underline{V_{i1}} = \frac{1}{3} V_{cc} = \underline{\underline{2V}}$$

$$\underline{\underline{V_{f1}}} = V_{Thev} \frac{R_6}{R_{Thev} + R_5 + R_6} + V_{cc} \frac{R_{Thev} + R_5}{R_{Thev} + R_5 + R_6} = 0.5 + 4 = \underline{\underline{4.5\ V}}$$

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

$$\left.\begin{array}{l} I_6 = \dfrac{V_{cc} - V_{TH}}{R_6} = \dfrac{2}{500} = 4\ mA \\ I_5 = \dfrac{V_{TH} - V_{THEV}}{R_{Thev} + R_5} = 2.5\ mA \\ I_1 = I_6 - I_5 = 1.5\ mA \end{array}\right\} \Rightarrow \underline{\underline{V_{COR1}}} = V_{TH} - R_1 I_1 = \underline{\underline{3.4\ V}}$$

$_{i1} < V_{cor1} < V_{f1}$

$2V < 3.4V < 4.5V$

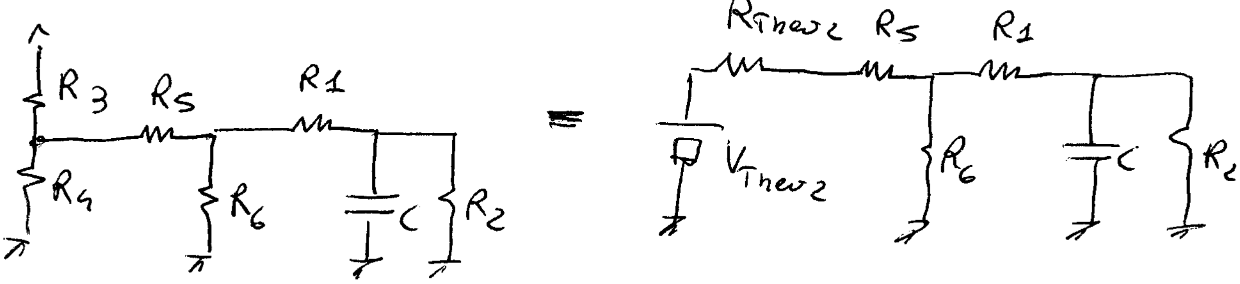
$$R_{V1} = R_1 + \left[R_6 \parallel (R_5 + R_{Thev}) \right] = 733.\bar{3}\ \Omega$$

$$\tau_1 = R_{V1} C = 6.01\bar{3} \times 10^{-4} s$$

$$T_1 = \tau_1 \ln\left(\frac{V_{i1} - V_{f1}}{V_{cor1} - V_{f1}} \right) = 4.9368 \times 10^{-4} s$$

2° CASO

$Q = \phi$, $D = \phi$ $\Big\}$ $V_{G1} = 6V$, $V_{S1} = \phi V$ $\Rightarrow V_{GS1} = 6V > V_T \Rightarrow Q_1$ ON



$\underline{V_{i2}} = V_{cor1} = \underline{3.4V}$

$\underline{V_{cor2}} = V_{i1} = \underline{2V}$

$$V_{Thev2} = V_{cc} \frac{R_4}{R_3 + R_4} = 1.5V$$

$$R_{Thev2} = R_3 \parallel R_4 = 750\,\Omega$$

$$\underline{V_{f2}} = V_{Thev2} \overbrace{\frac{1}{R_{Thev2} + R_5 + \left[R_6 \parallel (R_1 + R_2)\right]}}^{7.857 \times 10^{-4}} \overbrace{\frac{R_6}{R_6 + R_1 + R_2}}^{0.4\bar{5}} R_2 = \underline{0.107V}$$

$V_{i2} > V_{cor2} > V_{f2}$

$3.4V > 2V > 0.107V$

$$R_{V2} = R_2 \parallel \left[R_1 + R_6 \parallel (R_{Thev2} + R_5) \right] = 157.14\ \Omega$$

$$\tau_2 = 1.288 \times 10^{-4} s$$

$$T_2 = \tau_2 \ln\left(\frac{V_{i2} - V_{f2}}{V_{cor2} - V_{f2}} \right) = 7.134 \times 10^{-5} s$$

$$T = T_1 + T_2 = 5.6502 \times 10^{-4} s$$

$$\underline{f} = \underline{1769.84\ Hz}$$