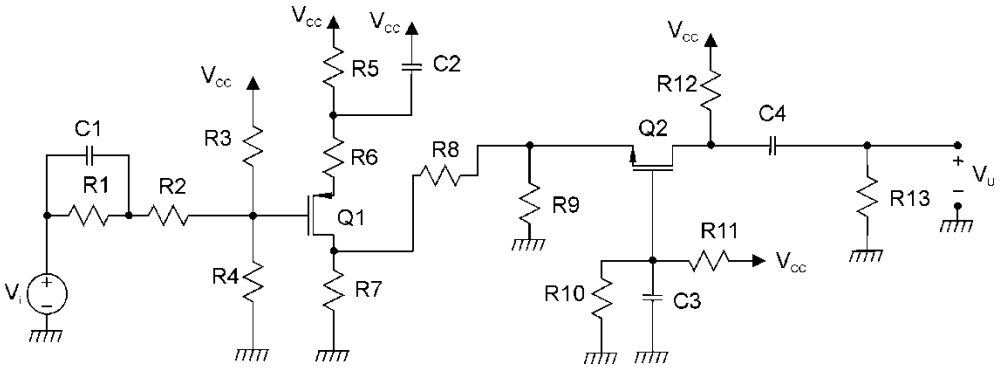
ELETTRONICA DIGITALE

Corso di Laurea in Ingegneria Informatica

Prova scritta del 20 febbraio 2023

Esercizio A



R1 = 9.9 kΩ	R2 = 100 Ω	R3 = 4 kΩ	R4 = 40 kΩ	R6 = 10 Ω	R7 = 1.5 kΩ	R8 = 1 kΩ
R9 = 30 kΩ	R10 = 20 kΩ	R11 = 20 kΩ	R12 = 4 kΩ	R13 = 30 kΩ	VCC = 18 V	

Q1 è un transistore MOS a canale p resistivo con V_{T1} = -1 V; Q2 è un transistore MOS a canale n resistivo con V_{T2} = 1 V; per entrambi i MOS la corrente di drain in saturazione è 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 R5 in modo che, in condizioni di riposo, la tensione sul drain di Q2 sia 10 V. Determinare, inoltre, il punto di riposo dei due transistori e verificarne la saturazione.
2) Determinare l'espressione e il valore di V_U/Vi alle frequenze per le quali C1, C2, C3 e C4 possono essere considerati dei corto circuiti.

Esercizio B

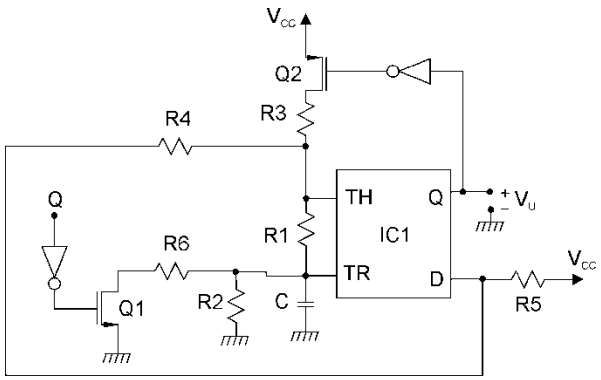
Progettare una porta logica in tecnologia CMOS, utilizzando la tecnica della pull-up network e della pull-down network, che implementi la funzione logica:

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

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

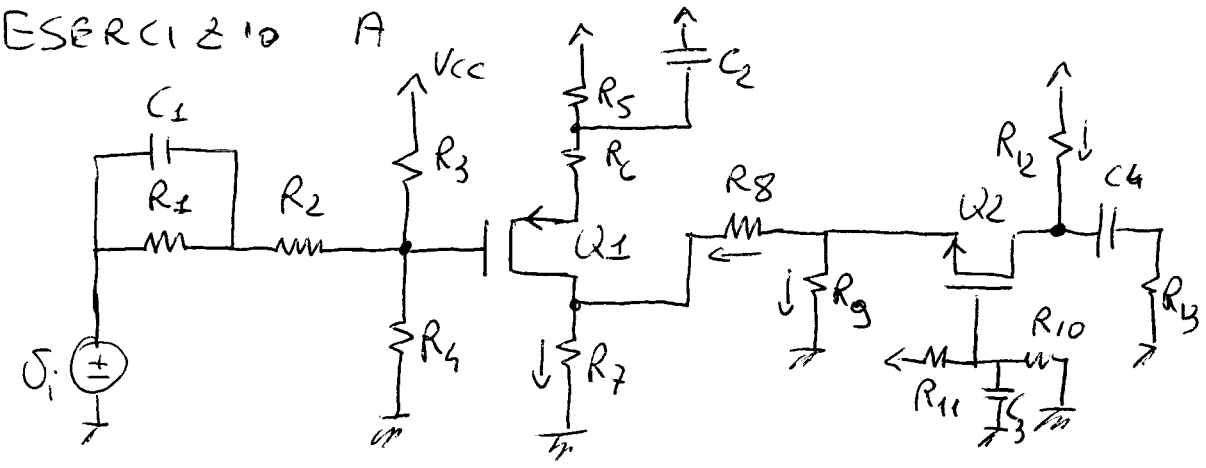
R1 = 400 Ω	R5 = 1 kΩ
R2 = 1.8 kΩ	R6 = 900 Ω
R3 = 2 kΩ	C = 22 nF
R4 = 1 kΩ	V_{CC} = 6 V



Il circuito IC_1 è un NE555 alimentato a V_{CC} = 6 V; Q1 ha R_{on} = 0 e V_{Tn} = 1V; Q2 ha R_{on} = 0 e V_{Tp} = −1V; gli inverter sono ideali. Verificare che il circuito si comporta come un multivibratore astabile e determinare la frequenza del segnale di uscita.

APPELLO 20/02/2023

ESERCIZIO A



$R_1 = 9.9\,k\Omega$
$R_2 = 100\,\Omega$
$R_3 = 4\,k\Omega$
$R_4 = 40\,k\Omega$
$R_6 = 10\,\Omega$
$R_7 = 1.5\,k\Omega$
$R_8 = 1\,k\Omega$
$R_9 = 30\,k\Omega$
$R_{10} = 20\,k\Omega$
$R_{11} = 20\,k\Omega$
$R_{12} = 4\,k\Omega$
$R_{13} = 30\,k\Omega$
$V_{CC} = 18\,V$

1) Det. R_5 per $V_{D2} = 10\,V$

$I_G = 0$

$$I_{12} = \frac{V_{CC} - V_{D2}}{R_{12}} = 2\,mA = I_{D2} \triangleq I_{S2}$$

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

$$V_{GS_2} = V_{T_2} \pm \sqrt{\frac{I_{D2}}{K}}$$

SCELGO SOLUZIONE "POSITIVA (+)" PERCHÈ Q_2 È UN NMOS

EQUINDI CONDUCE PER $V_{GS} \geq V_T$

$$V_{GS_2} = V_{T_2} + \sqrt{\frac{I_{D2}}{K}} = 3\,V$$

$$V_G = V_{CC}\,\frac{R_{10}}{R_{10} + R_{11}} = 9\,V$$

$$V_{S_2} = V_G - V_{GS} = 9 - 3 = 6\,V$$

$$V_{DS_2} = V_D - V_S = 10 - 6 = 4\,V$$

Q_2: $I_{D2} = 2\,mA$, $V_{DS} = 4\,V$, $V_{GS} = 3\,V$, $g_{m_2} = 2 \times 10^{-3}\,A/V$

VERIFICA SATURAZIONE: $V_{DS} \geq (V_{GS} - V_T)$

$4\,V > (3-1) = 2\,V \Rightarrow$ VERIFICA OK

$$g_{m_2} = 2K(V_{GS_2} - V_{T_2}) = 2 \times 10^{-3}\,A/V$$

$$I_g = \frac{V_S}{R_g} = \frac{6}{30000} = 0.2\,mA$$

$$I_8 = I_{S_2} - I_g = 1.8\,mA$$

$$V_{D1} = V_{S2} - R_8 I_8 = 4.2\,V$$

$$I_7 = \frac{V_{D1}}{R_7} = 2.8\,mA$$

$I_{D1} = I_7 - I_8 = 1\,mA$

$I_{G1} = 0 \Rightarrow I_{S1} = I_{D1} = 1\,mA$

$$V_{G1} = V_{CC}\,\frac{R_4 \| (R_1+R_2)}{R_3 + [R_4 \| (R_1+R_2)]} = 12\,V$$

hp: Q_1 SATURO $\Rightarrow I_{D1} = K(V_{GS1} - V_{T1})^2$

$$\Rightarrow V_{GS1} = V_{T1} \pm \sqrt{\frac{I_{D1}}{K}}$$

SCELGO LA SOLUZIONE "NEGATIVA (-)" PERCHÈ Q_1 È UN PMOS E QUANDO CONDUCE PER $V_{GS} \leq V_T$

$$\Rightarrow V_{GS1} = V_{T1} - \sqrt{\frac{I_{D1}}{K}} = -2.414\,V$$

$V_{S1} = V_{G1} - V_{GS1} = 12 - (-2.414) = 14.414\,V$

$V_{DS1} = V_{D1} - V_{S1} = 4.2 - (14.414) = -10.214\,V$

VERIFICA SATURAZIONE Q_1: $V_{DS1} \leq (V_{GS1} - V_{T1})$

$-10.214\,V < [-2.414 - (-1)] = -1.414\,V \Rightarrow$ OK

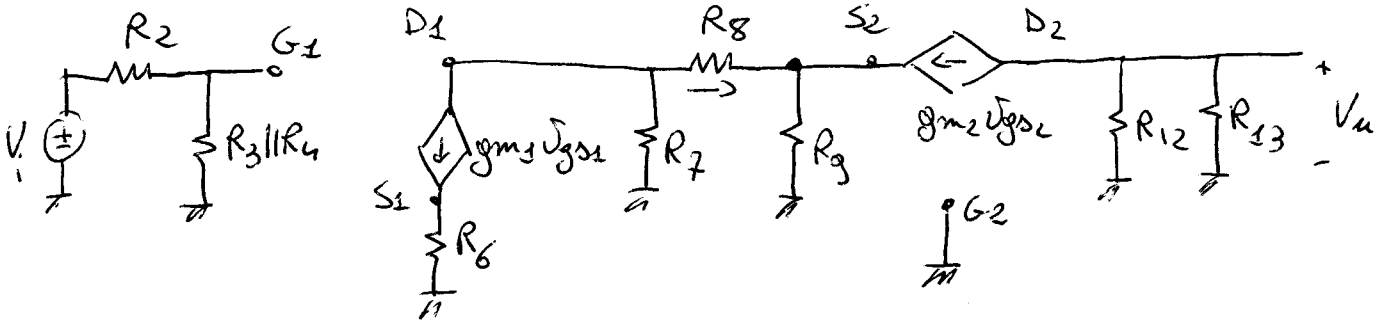
$g_{m1} = 2K\,|V_{GS1} - V_{T1}| = 1.414 \times 10^{-3}\ A/V$

$$R_5 + R_6 = \frac{V_{CC} - V_{S1}}{I_{D1}} = 3586\,\Omega$$

$R_5 = 3586 - R_6 = \underline{3576\,\Omega}$

Q_1: $\begin{cases} I_{D1} = 1\,mA \\ V_{DS1} = -10.214\,V \\ V_{GS1} = -2.414\,V \\ g_{m1} = 1.414 \times 10^{-3}\ A/V \end{cases}$

2) Det V_u/V_i per C_1, C_2, C_3 e C_4 CORTOCIRCUITATI



$$V_u = -g_{m2} v_{gs2} (R_{12} \| R_{13})$$
$$v_{g2} = 0 \Rightarrow v_{gs2} = -v_{s2}$$
$$\Rightarrow V_u = g_{m2} v_{s2} (R_{12} \| R_{13})$$

$$v_{s2} = i_8 \left(R_9 \| \frac{1}{g_{m2}}\right)$$

$$i_8 = (-g_{m1} v_{gs1}) \frac{R_7}{R_7 + R_8 + \left(R_9 \| \frac{1}{g_{m2}}\right)}$$

$$v_{s1} = (g_{m1} v_{gs1}) R_6$$
$$v_{gs1} = v_{g1} - v_{s1} = v_{g1} - g_{m1} v_{gs1} R_6$$
$$\Rightarrow v_{gs1} = \frac{v_{g1}}{1 + g_{m1} R_6}$$

$$v_{g1} = v_i \frac{R_3 \| R_4}{R_2 + (R_3 \| R_4)}$$

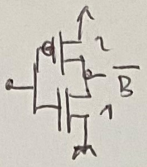
$$\frac{V_u}{V_i} = g_{m2} (R_{12} \| R_{13}) \left(R_9 \| \frac{1}{g_{m2}}\right) (-g_{m1}) \frac{R_7}{R_7 + R_8 + \left(R_9 \| \frac{1}{g_{m2}}\right)} \frac{1}{1 + g_{m1} R_6}$$

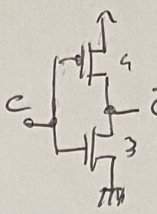
2×10^{-3} · 3523.4 · 491.8 · 1.414×10^{-3} · 0.5013 · 0.986 · 0.9732

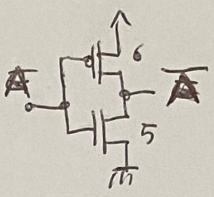
$$\cdot \frac{R_3 \| R_4}{R_2 + (R_3 \| R_4)} = -2.36$$

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

$N = 2 \times (9+3) = 24$

INV: B 

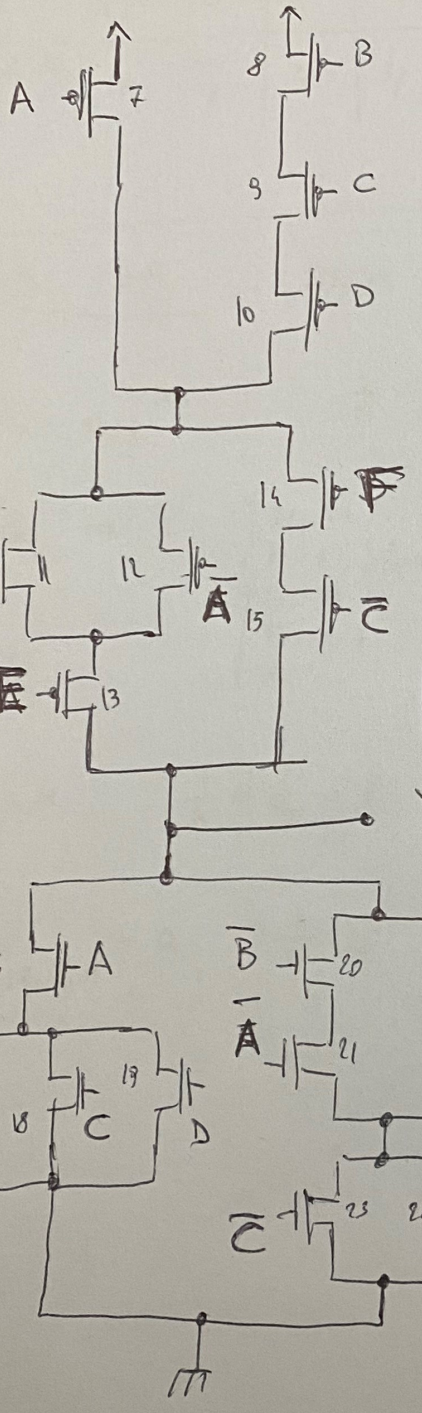




$\left(\frac{W}{C}\right)_{1,3,5} = M = 2$

$\left(\frac{W}{C}\right)_{2,4,6} = P = 5$

~~8,9,10,11,13~~



PUN:

* PERCORSI DA 5: $\begin{cases} 8-9-10-11-13 & \text{INP. } (B \text{ E } \overline{B}) \\ 8-9-10-12-13 & \\ 8-9-10-14-15 & \text{INP. } (C \text{ E } \overline{C}) \end{cases}$

$\left(\frac{W}{C}\right)_{8,9,10,12,13} = x \qquad \frac{1}{x} + \frac{1}{x} + \frac{1}{x} + \frac{1}{x} + \frac{1}{x} = \frac{5}{x} = \frac{1}{P}$

$x = \left(\frac{W}{C}\right)_{8,9,10,12,13} = 5P = 25$

* PERCORSO DA 3: $\begin{cases} 7-11-13 \\ 7-12-13 \\ 7-14-15 \end{cases}$ INPUTS (A E $\overline{A}$)

OPZ. (A): DIMENSIONO 7-11 USANDO 7-11-13 E POI DIMENSIONO 14-15 USANDO 7-14-15

OPZ. (B): DIMENSIONO 7-14-15 E POI DIMENSIONO 11 USANDO 7-11-13

OPZ. A:

(7) (11) (13)

$\left(\frac{W}{C}\right)_{7,11} = z \qquad \frac{1}{z} + \frac{1}{z} + \frac{1}{5P} = \frac{2}{z} + \frac{1}{5P} = \frac{5}{5P}$

$\frac{2}{z} = \frac{4/2}{5P} \rightarrow z = \left(\frac{W}{C}\right)_{7,11} = \frac{5}{2}P = 12.5$

(14) (13) (7)

$\left(\frac{W}{C}\right)_{14,15} = t \qquad \frac{1}{t} + \frac{1}{t} + \frac{1}{\frac{5P}{2}} = \frac{2}{t} + \frac{2}{5P} = \frac{5}{5P}$

$\frac{2}{t} = \frac{3}{5P} \rightarrow t = \left(\frac{W}{C}\right)_{14,15} = \frac{10P}{3} = 16,\hat{6}$

OPZ (B):

$\left(\frac{W}{C}\right)_{7,14,13} = f \qquad \frac{1}{P} + \frac{1}{f} + \frac{1}{P} = \frac{3}{P} = \frac{1}{P}$

$f = \left(\frac{W}{C}\right)_{7,14,13} = 3P = 15$

$\left(\frac{W}{C}\right)_{11} = h$ (11) (7) (13)

$$\frac{1}{h} + \frac{1}{3p} + \frac{1}{5p} = \frac{15}{15p} \rightarrow \frac{1}{h} = \frac{15 - 5 - 3}{15p} = \frac{7}{15p}$$

$$h = \left(\frac{W}{C}\right)_{11} = \frac{15p}{7} = 10,714$$

	7	11	14	13	TOT
OPZA	$\frac{5}{2}p = 12.5$	$\frac{5p}{2}$	$\frac{10p}{3}$	$\frac{10p}{3}$	$\frac{3\times2\times5 + 2\times2\times10}{6}p = 58,\hat{3}$
OPZ. B	$3p$	$\frac{15p}{7}$	$7p$	$3p$	$\frac{(7\times3+15)p}{7} = 55,714$

→ DA PREFERIRE OPZ. B (AD AREA MINIMA)

DIM PDN.

PERCORSI DA 3: 20-21-23, 20-21-24 } POSSIBILI

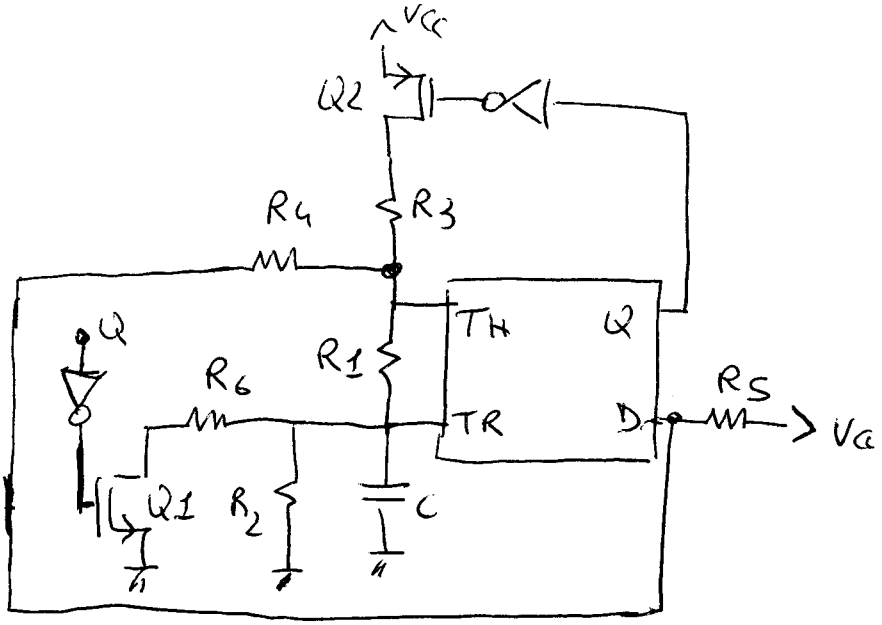
$$\left(\frac{W}{C}\right)_{20,21,23,24} = m \qquad \frac{1}{m} + \frac{1}{m} + \frac{1}{m} = \frac{3}{m} = \frac{1}{n} \rightarrow m = \left(\frac{W}{C}\right)_{20,21,23,24} = 3n = 6$$

PERCORSI DA 2: 22-24, 22-23, 16-17, 16-18, 16-19 } POSSIBILI, 13 E 24 GIÀ DIMENSIONATI

$$\left(\frac{W}{C}\right)_{22} = k \qquad \frac{1}{k} + \frac{1}{3n} = \frac{3}{3n} \rightarrow \frac{1}{k} = \frac{2}{3n} \rightarrow k = \left(\frac{W}{C}\right)_{22} = \frac{3n}{2} = 3$$

$$\left(\frac{W}{C}\right)_{16,17,18,19} = a \qquad \frac{1}{a} + \frac{1}{a} = \frac{2}{a} = \frac{1}{n} \rightarrow a = \left(\frac{W}{C}\right)_{16,17,18,19} = 2n = 4$$

ESERCIZIO C



$R_1 = 400\,\Omega$

$R_2 = 1.8\,K\Omega$

$R_3 = 2\,K\Omega$

$R_4 = 1\,K\Omega$

$R_5 = 1\,K\Omega$

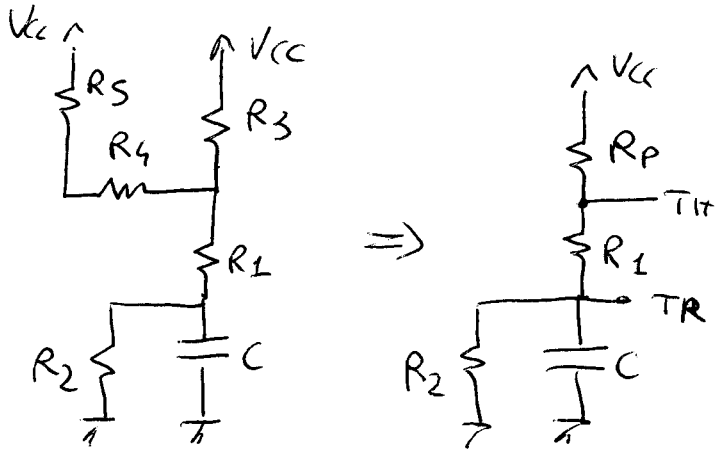
$C = 22\,nF$

$V_{cc} = 6\,V$

$R_6 = 900\,\Omega$

1ª FASE

$$\begin{cases} Q = 1 \\ D = HI \end{cases} \quad \begin{array}{l} \Rightarrow V_{G1} = 0V \quad V_{S1} = 0V \Rightarrow V_{GS1} = 0V < V_{T1} = 1V \Rightarrow Q_1 \text{ OFF} \\ V_{G2} = 0V \quad V_{S2} = 6V \Rightarrow V_{GS2} = -6 < V_{T2} = -1V \Rightarrow Q_2 \text{ ON} \end{array}$$



$R_p = R_3 \,||\, (R_4 + R_5) = 1\,K\Omega$

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

$$V_{f1} = V_{cc} \frac{R_2}{R_p + R_1 + R_2} = 3.375V$$

$$\left.\begin{array}{l} V_{COR1} = V_{TH} - R_1 I_1 \\ I_1 = \dfrac{V_{cc} - V_{TH}}{R_f} = 2mA \end{array}\right\} \Rightarrow V_{COR1} = 4 - 0.8 = 3.2V$$

$$V_{i1} < V_{COR1} < V_{f1}$$

$$2V < 3.2V < 3.375V \quad \underline{OK}$$

$R_{V1} = R_2 \| (R_1 + R_p) = 787.5\ \Omega$

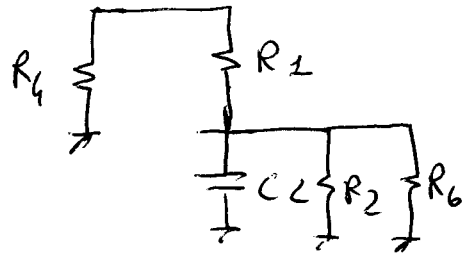
$\tau_1 = C R_{V1} = 17.325\ \mu s$

$T_1 = \tau_1 \ln\left(\frac{V_{i1} - V_{f1}}{V_{con1} - V_{f1}}\right) = 35.714\ \mu s$

2ª fase

$Q = \phi$ $V_{G1} = 6V$ $V_{S1} = \phi V$ $\Rightarrow V_{GS1} = 6V > V_{T1} = 1V \Rightarrow Q_1$ ON

$D = \phi$ $V_{G2} = 6V$ $V_{S2} = 6V$ $\Rightarrow V_{GS2} = \phi V > V_{T2} = -1V \Rightarrow Q_2$ OFF



$V_{i2} = V_{con1} = 3.2V$

$V_{f2} = \phi V$

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

VERIFICA: $V_{i2} < V_{con2} < V_{f2}$

$3.2V < 2V < \phi V$

$R_{V2} = R_2 \| R_6 \| (R_1 + R_4) = 420\ \Omega$

$\tau_2 = 9.24\ \mu s$

$T_2 = \tau_2 \ln\left(\frac{V_{i2} - V_{f2}}{V_{con2} - V_{f2}}\right) = 4.34\ \mu s$

$T = T_1 + T_2 = 40.054\ \mu s$

$f = \frac{1}{T} = 24966\ Hz$