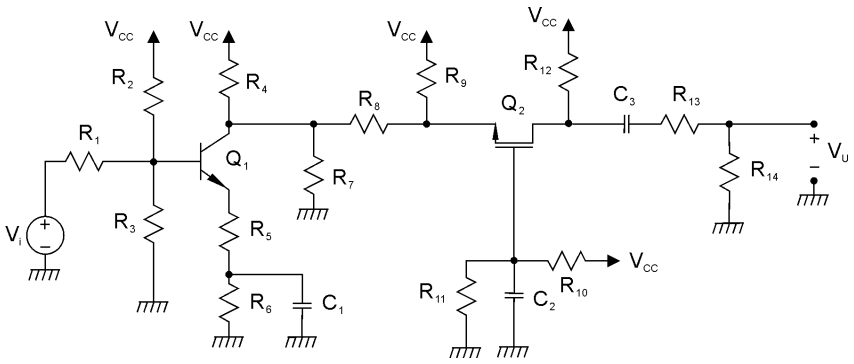
ELETTRONICA DIGITALE

Corso di Laurea in Ingegneria Informatica

Prova scritta del 13 settembre 2018

Esercizio A

R_1 = 10 kΩ	R_9 = 36 kΩ
R_2 = 13750 Ω	R_{10} = 10 kΩ
R_4 = 18900 Ω	R_{11} = 20 kΩ
R_5 = 75 Ω	R_{12} = 3 kΩ
R_6 = 1700 Ω	R_{13} = 1 kΩ
R_7 = 11400 Ω	R_{14} = 20 kΩ
R_8 = 200 Ω	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 $V_T = 1$ 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_3 in modo che, in condizioni di riposo, la tensione sul drain di Q_2 sia 12 V. Determinare, inoltre, il punto di riposo dei due transistori e verificare la saturazione di Q_2. (R: R_3 = 7481 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 = -7.18)

Esercizio B

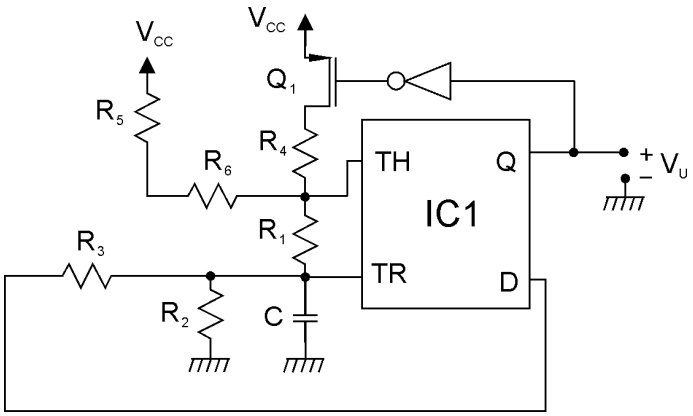
Progettare una porta logica in tecnologia CMOS, utilizzando la tecnica della pull-up network e della pull-down network, che implementi la funzione logica:

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

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. (R: N = 20)

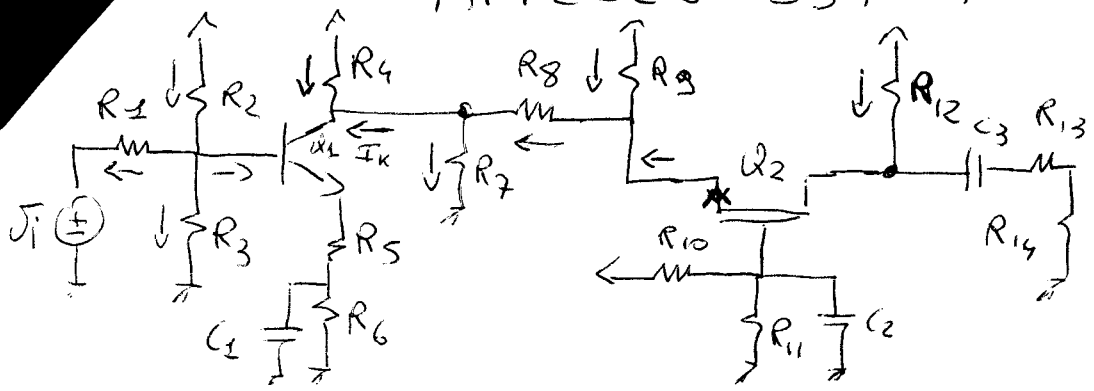
Esercizio C

R_1 = 400 Ω	R_5 = 4 kΩ
R_2 = 4 kΩ	R_6 = 4 kΩ
R_3 = 1 kΩ	C = 470 nF
R_4 = 2 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; l'inverter è ideale. Determinare la frequenza del segnale di uscita del multivibratore in figura. (R: f = 901.54 Hz)

APPELLO 13/09/2018



$R_1 = 10\,k\Omega$
$R_2 = 13750\,\Omega$
$R_4 = 18300\,\Omega$
$R_5 = 75\,\Omega$
$R_6 = 1700\,\Omega$
$R_7 = 11400\,\Omega$
$R_8 = 200\,\Omega$
$R_9 = 36\,k\Omega$
$R_{10} = 10\,k\Omega$
$R_{11} = 20\,k\Omega$
$R_{12} = 3\,k\Omega$
$R_{13} = 1\,k\Omega$
$R_{14} = 20\,k\Omega$
$V_{CC} = 18\,V$
$K = 0.5\ mA/V^2$

.) Calcolare R_3 per $V_D = 12V$

$$I_{12} = \frac{V_{CC} - V_D}{R_{12}} = 2\,mA$$

hp: SATURAZIONE

$$V_{GS} = V_T + \sqrt{\frac{I_{12}}{K}} = 3V$$

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

$$V_S = V_G - V_{GS} = 9V$$

$V_{DS} = V_D - V_S = 12 - 9 = 3V > V_{GS} - V_T = 2V \Rightarrow$ hp ok

$$I_9 = \frac{V_{CC} - V_S}{R_9} = 250\,\mu A$$

$$I_8 = I_9 + I_S = 2.25\,mA$$

$$V_C = V_S - R_8 I_8 = 8.55V$$

$$I_7 = \frac{V_C}{R_7} = 750\,\mu A$$

$$I_K = I_8 - I_7 = 1.5\,mA$$

$$I_4 = \frac{V_{CC} - V_C}{R_4} = 0.5\,mA$$

$$I_C = I_4 + I_K = 2\,mA$$

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

$$V_E = I_E (R_5 + R_6) = 3.55V$$

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

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

Q_1:
- $I_C = 2\,mA$
- $V_{CE} = 5V$
- $I_B = 6.8365\,\mu A$
- $h_{FE} = 290$
- $h_{ie} = 4800\,\Omega$
- $h_{fe} = 300$

$= V_C - V_E = 8.55 - 3.55 = 5V$

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

$$I_B = \frac{I_C}{h_{FE}} = 6.896\,\mu A$$

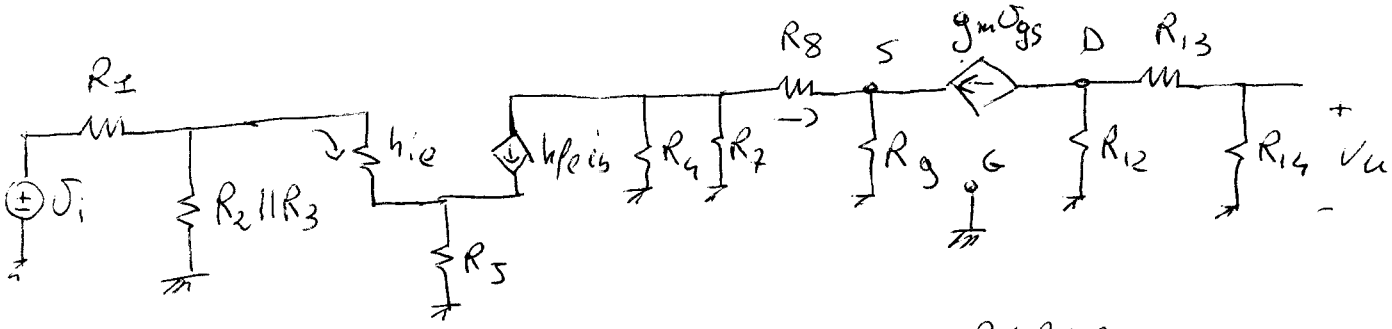
$$V_B = V_E + V_f = 4.25V$$

$$I_1 = \frac{V_B}{R_1} = 425\,\mu A$$

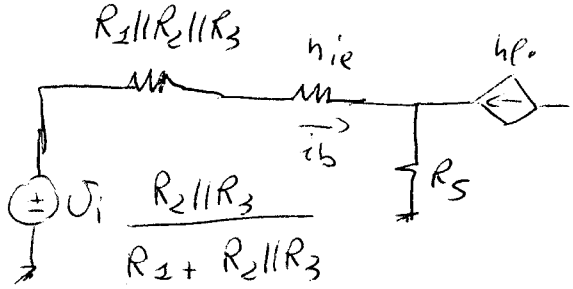
$$I_2 = \frac{V_{CC} - V_B}{R_2} = 1\,mA$$

$$I_3 = I_2 - I_1 - I_B = 5.681 \times 10^{-4} A$$

$$R_3 = \frac{V_B}{I_3} = 7481.03\,\Omega$$



$$V_u = (-g_m V_{gs}) \frac{R_{12}}{R_{12} + R_{13} + R_{14}} R_{14}$$



$V_g = \phi$

$$V_s = I_8 \left(R_9 \| \frac{1}{g_m}\right)$$

$$I_8 = (-h_{fe} i_b) \frac{(R_4 \| R_7)}{(R_4 \| R_7) + R_8 + \left(R_9 \| \frac{1}{g_m}\right)}$$

$$i_b = V_i \frac{R_2 \| R_3}{R_1 + R_2 \| R_3} \frac{1}{(R_2 \| R_2 \| R_3) + h_{ie} + R_5(h_{fe} + 1)}$$

2×10^{-3} 2500 493.15 300 0.991118

$$A_v = (-g_m)\frac{R_{12}\,R_{14}}{R_{12}+R_{13}+R_{14}}(-)\left(R_g \| \frac{1}{g_m}\right)(-h_{fe})\frac{R_4 \| R_7}{R_4 \| R_7 + R_8 + \left(R_g \| \frac{1}{g_m}\right)}$$

0.326 3.2638×10^{-5}

$$\frac{R_2 \| R_3}{R_1 + R_2 \| R_3}\cdot\frac{1}{(R_1 \| R_2 \| R_3) + h_{ie} + R_5(h_{fe}+1)} = -7.18$$

$$|V_u|_{dB} = 17.12\ dB$$

EJERCICIO B

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

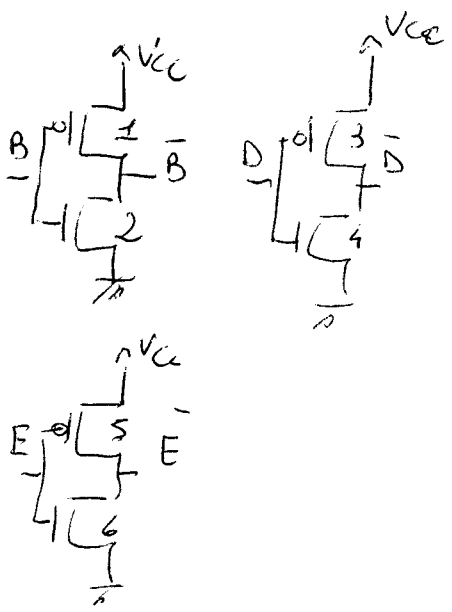
$$= \bar{A}B(\bar{C}+\bar{D}E) + \bar{A}BC + AB\bar{D}E + \bar{C}\bar{E} + \bar{C}D =$$

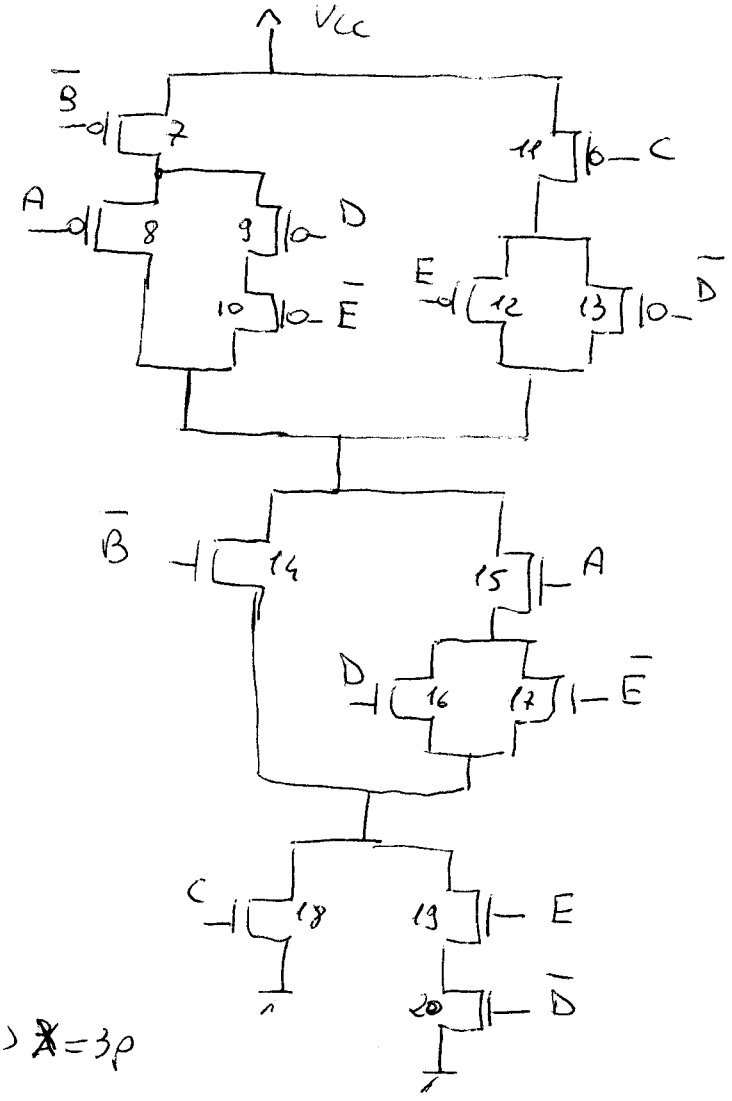
$$= \bar{A}B\bar{C} + \bar{A}B\bar{D}E + \bar{A}BC + AB\bar{D}E + \bar{C}\bar{E} + \bar{C}D =$$

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

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

MOS: 14 + 6 = 20





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

$\left(\frac{W}{L}\right)_{2,4,6} = n = 2$

} INVERTER

·) PUN

-) $Q_7 - Q_9 - Q_{10}$ $\quad \frac{1}{x} + \frac{1}{x} + \frac{1}{x} = \frac{1}{p} \Rightarrow x = 3p$

$\left(\frac{W}{L}\right)_{7,9,10} = 3p = 15$

-) $Q_7 - Q_8$ $\quad \frac{1}{y} + \frac{1}{3p} = \frac{1}{p} \Rightarrow y = \frac{3}{2}p = 7.5$

$\left(\frac{W}{L}\right)_8 = 7.5$

-) $Q_{12} - Q_{13}$ $\quad \frac{1}{z} + \frac{1}{z} = \frac{1}{p} \Rightarrow z = 2p = 10$ $\quad \left(\frac{W}{L}\right)_{11,12,13} = 10$

$Q_{11} - Q_{12}$

-) $Q_{15} - Q_{16} - Q_{19} - Q_{20}$ NON È POSSIBILE × D e $\bar{D}$

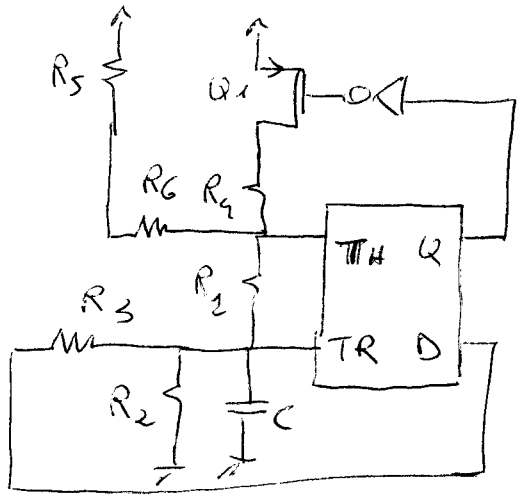
-) $Q_{15} - Q_{17} - Q_{19} - Q_{20}$ = = = = E e $\bar{E}$

-) $Q_{15} - Q_{16} - Q_{18}$
$Q_{15} - Q_{17} - Q_{18}$
$Q_{14} - Q_{19} - Q_{20}$

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

$\left(\frac{W}{L}\right)_{15,16,17,18,19,20} = 3n = 6$

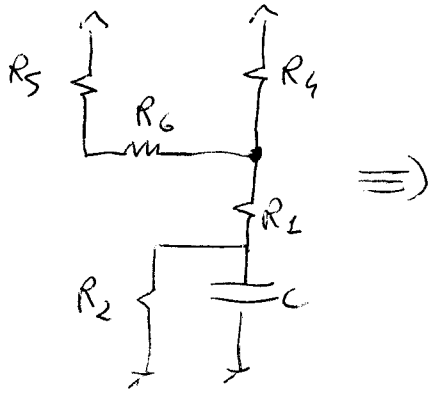
ESERCIZIO C



$R_1 = 400\,\Omega$
$R_2 = 4\,K\Omega$
$R_3 = 1\,K\Omega$
$R_4 = 2\,K\Omega$
$R_5 = 4\,K\Omega$
$R_6 = 4\,K\Omega$
$C = 470\,nF$

1) $Q = 1 \Rightarrow V_G = 0$, $V_S = V_{CC} \Rightarrow V_{GS} = -V_{CC} = -6V < V_T = -1V \Rightarrow Q_1$ OK

$D = H\bar{I}$



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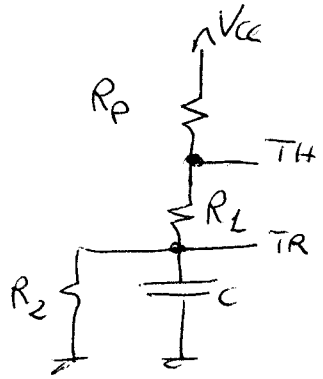

$R_P = R_4 \,||\, (R_5 + R_6) = 1600\,\Omega$

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

$V_P = V_{CC} \frac{R_2}{R_1 + R_2 + R_P} = 4V$

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

$I_1 = \frac{V_{CC} - V_{TH}}{R_P} = 1.25\,mA \Rightarrow V_{CONT} = V_{TH} - R_1 I_1 = 3.5V$

$R_{VC} = R_2 \,||\, [R_1 + R_P] = 1333.\bar{3}\,\Omega$

$\tau_1 = R_{VC} \cdot C = 6.26 \times 10^{-4}\ s$

$T_1 = \tau_1 \ln\left(\frac{V_i - V_f}{V_{con} - V_f}\right) = 8.6874 \times 10^{-4}\ s$

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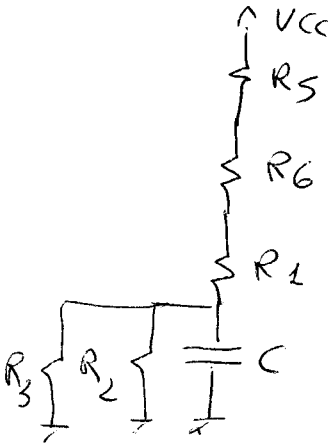
2) $Q = \phi$ $V_G = V_{cc}$ $V_S = V_{cc}$ $\Rightarrow V_{GS} = \phi \lesssim V_T = -1V$ $\Rightarrow Q_1$ OFF

$D = \phi$



$V_i = 3.5V$

$V_{con} = 2V$

$V_f = V_{cc} \dfrac{R_2 \| R_3}{(R_2 \| R_3) + R_1 + R_5 + R_6} = 0.5217V$

$R_{VC_2} = R_2 \| R_3 \| (R_1 + R_5 + R_6) = 730.43\ \Omega$

$\tau_2 = R_{VC_2} C = 3.433 \times 10^{-4}\ s$

$T_2 = \tau_2 \ln\left(\frac{V_i - V_f}{V_{con} - V_f}\right) = 2.4047 \times 10^{-4}\ s$

$T = T_1 + T_2 = 1.10921 \times 10^{-3}\ s$

$f = \frac{1}{T} = 901.54\ Hz$