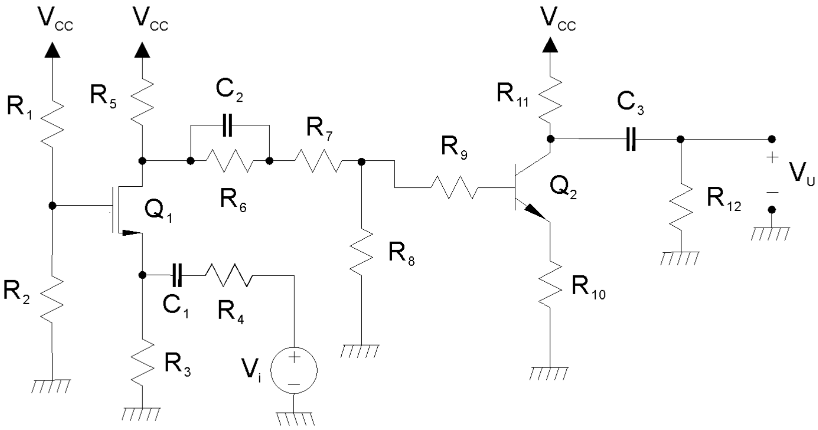
ELETTRONICA DIGITALE
Corso di Laurea in Ingegneria Informatica

Prova scritta del 10 settembre 2013

Esercizio A

$R_1 + R_2 = 100\ k\Omega$	
$R_3 = 2\ k\Omega$	$R_{10} = 2\ k\ \Omega$
$R_4 = 50\ \Omega$	$R_{11} = 4.5\ k\ \Omega$
$R_5 = 2\ k\Omega$	$R_{12} = 20\ k\ \Omega$
$R_6 = 380\ k\Omega$	$C_1 = 47$ nF
$R_7 = 100\ \Omega$	$C_2 = 150$ nF
$R_8 = 490\ k\Omega$	$C_3 = 6.8$ nF
$R_9 = 29\ k\Omega$	$V_{CC} = 18$ V



Q_1 è un transistore MOS a canale n resistivo, con la corrente di drain in saturazione data da $I_{DS} = k(V_{GS}-V_T)^2$ con $k = 0.5\ mA/V^2$ e $V_T = 1V$. Q_2 è un transistore BJT BC109B resistivo con $h_{re} = h_{oe} = 0$.
Con riferimento all'amplificatore in figura:
1) Calcolare il valore delle resistenze R_1 e R2 in modo che, in condizioni di riposo, la tensione sul collettore di Q_2 sia $V_C = 9$ V. Determinare, inoltre il punto di riposo dei due transistori e verificare la saturazione di Q_1. (R: $R_1 = 43213\ \Omega$; R2 = $56787\ \Omega$)
2) Determinare il guadagno 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 = - 7.69)
3) (**<u>Solo per 12 CFU</u>**) Determinare la funzione di trasferimento V_U/V_i e tracciarne il diagramma di Bode quotato asintotico del modulo. (R: $f_{z1} = 0$ Hz; $f_{p1} = 9031.75$ Hz; $f_{z2} = 2.79$ Hz; $f_{p2} = 6.598$ Hz; $f_{z3} = 0$ Hz; $f_{p3} = 955.31$ Hz)

Esercizio B

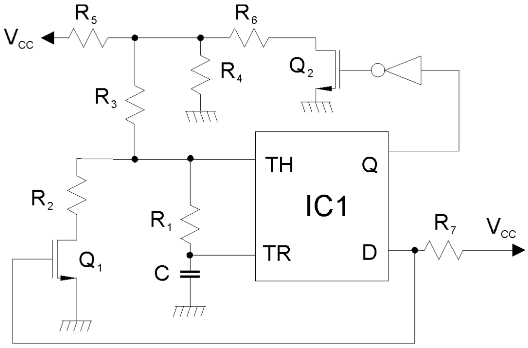
Progettare una porta logica in tecnologia CMOS, utilizzando la tecnica della pull-up network e della pull-down network, che implementi la funzione logica:

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

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.

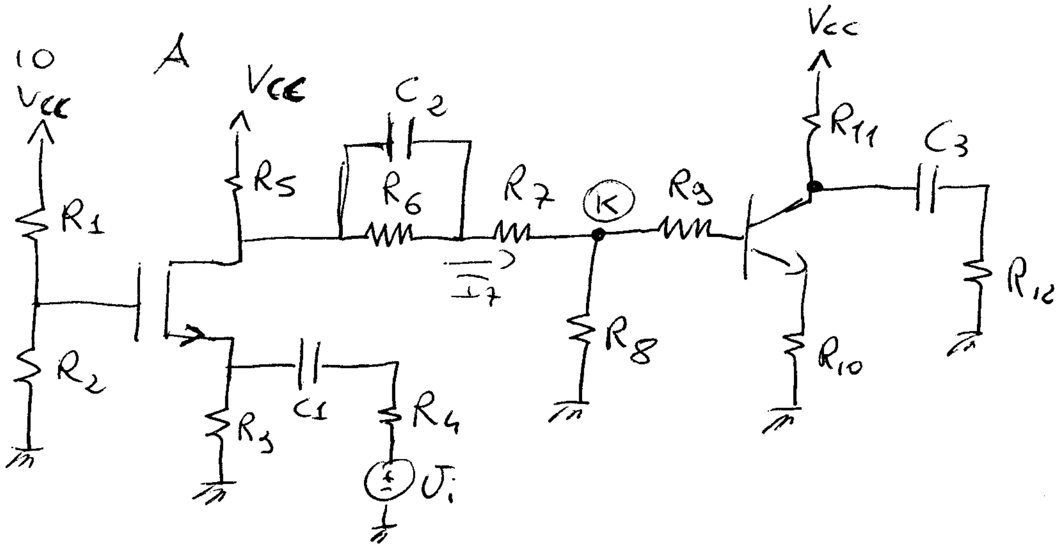
Esercizio C

$R_1 = 500\ \Omega$	$R_6 = 10\ \Omega$
$R_2 = 4\ k\Omega$	$R_7 = 1\ k\Omega$
$R_3 = 300\ \Omega$	C = 680 nF
$R_4 = 1\ k\Omega$	$V_{CC} = 5$ V
$R_5 = 100\ \Omega$	



Il circuito IC_1 è un NE555 alimentato a V_{CC} = 5V, Q_1 e Q_2 hanno 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 = 2931.44 Hz)

ERCI 210 A



$V_{cc} = 18V$

$R_1 + R_2 = 100K$

$R_3 = 2K$

$R_4 = 50\Omega$

$R_5 = 2K$

$R_6 = 380K$

$R_7 = 100$

$R_8 = 490K$

$R_9 = 29K$

$R_{10} = 2K$

$R_{11} = 4.5K$

$R_{12} = 20K$

$I_D = K(V_{GS} - V_T)^2$

$K = 0.5 \times 10^{-3} \frac{A}{V^2}$

$C_1 = 47nF$

$C_2 = 150\,nF$

$C_3 = 6.8\,nF$

·) Determina R_1 e R_2 in modo che $V_C = 9V$

$I_C = I_{R11} = \frac{V_{CC} - V_C}{R_{11}} = \frac{9}{4.5 \times 10^3} = 2\,mA$

$I_C \simeq I_E$

$V_E = I_E R_{10} = 4V$

$\left.\begin{array}{l} V_{CE} = 5V \\ I_C = 2mA \end{array}\right\} \Rightarrow \begin{array}{l} \beta_F = 290 \\ I_B = \frac{I_C}{\beta_F} = 6.896\,\mu A \end{array}$

$V_B = V_E + V_\gamma = 4.7V$

$V_K = V_B + R_9 I_B = 4.9V$

$I_8 = \frac{V_K}{R_8} = 10\,\mu A$

$I_7 = I_8 + I_B = 16.896\,\mu A$

$V_D = (R_6 + R_7) I_7 + V_K = 11.322V$

$I_5 = \frac{V_{cc} - V_D}{R_5} = 3.339\,mA$

$I_D = I_5 - I_7 = 3.322\,mA$

$V_{GS} - V_T = +\sqrt{\frac{I_D}{K}} = 2.5776V$

$V_{GS} = 3.5776\,V$

$V_S = I_D R_3 = 6.644V$

$V_G = 10.2216$

~~V_{GS}~~

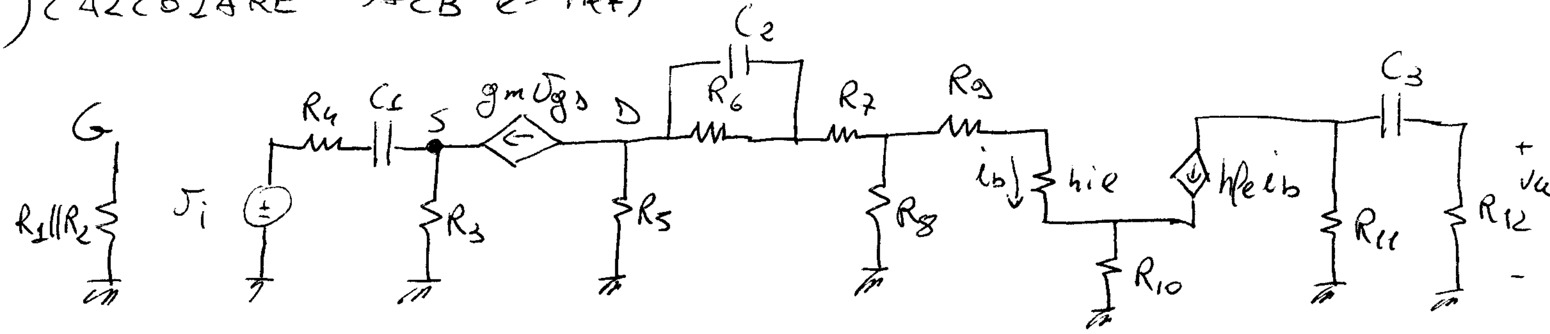
$V_{DS} = 4.678\ V \quad (> V_{GS} - V_T = 2.5776\ V)$

$$V_G = \frac{V_{CC}}{(R_1+R_2)} \cdot R_2 \Rightarrow R_2 = \frac{V_G(R_1+R_2)}{V_{CC}} = 56786.\bar{6}\ \Omega$$

$$R_1 = 43213.\bar{3}$$

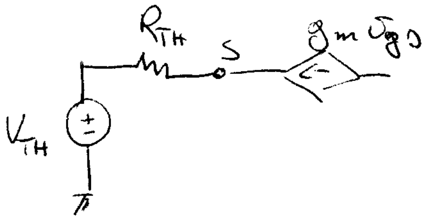
3) CALCOLARE A_{CB}

$h_{ie} = 4800 \quad h_{fe} = 300 \quad g_m = 2.5776 \times 10^{-3}\ \frac{A}{V}$



$$V_u = -(h_{fe}\, i_b)(R_{11} \| R_{12})$$

$$i_b = -g_m v_{gs} \left[\frac{R_5}{R_5 + R_7 + R_8 \| [R_9 + h_{ie} + R_{10}(h_{fe}+1)]} \cdot \frac{R_8}{R_8 + R_9 + h_{ie} + R_{10}(h_{fe}+1)} \right]$$



$$V_{TH} = \frac{v_i R_3}{R_3 + R_4} \qquad R_{TH} = R_3 \| R_4$$

$$v_g = \phi$$

$$v_s = V_{TH} + R_{TH}\, g_m (v_g - v_s) = \frac{V_{TH}}{1 + g_m R_{TH}} = \left(\frac{v_i R_3}{R_3 + R_4} \right) \frac{1}{1 + g_m (R_3 \| R_4)} = v_i \frac{R_3}{R_3 + R_4 + g_m R_3 R_4}$$

$$A_{CB} = \frac{V_u}{V_i} = \overbrace{-h_{fe}(R_{11} \| R_{12})}^{2840.62} \cdot g_m \left[\overbrace{\frac{R_5}{R_5 + R_7 + R_8 \| [R_9 + h_{ie} + R_{10}(h_{fe}+1)]}}^{7.1728 \times 10^{-3}} \cdot \overbrace{\frac{R_8}{R_8 + R_9 + h_{ie} + R_{10}(h_{fe}+1)}}^{0.435246} \right.$$

$$\left. \underbrace{\cdot \frac{R_3}{R_3 + R_4} \frac{1}{1 + g_m (R_3 \| R_4)}}_{0.36664} \right] = -7.6856$$

$$|A_{CB}|_{dB} = 17.71\ dB$$

47 nF

$f_{z1} = \phi$

$f_{p1} = \dfrac{1}{2\pi C_1 R_{vc1}} = 9031.75 \text{ Hz}$

$R_{vc1} = R_4 + \left(R_3 \parallel \dfrac{1}{gm}\right) = 374.93\ \Omega$

C_2 : 150 nF

$f_{z2} = \dfrac{1}{2\pi C_2 R_6} = 2.793 \text{ Hz}$

$f_{p2} = \dfrac{1}{2\pi C_2 R_{vc2}} = 6.5975 \text{ Hz}$

$R_{vc2} = R_6 \parallel \left[R_5 + R_7 + \left\{R_8 \parallel \left[R_9 + h_{ie} + R_{10}(h_{fe}+1)\right]\right\}\right] = 160823.39\ \Omega$

C_3 : 6.8 nF

$f_{z3} = \phi$

$f_{p3} = \dfrac{1}{2\pi C_3 R_{vc3}} = 955.31 \text{ Hz}$

$R_{vc3} = R_{11} + R_{12} = 24.5\ k\Omega$

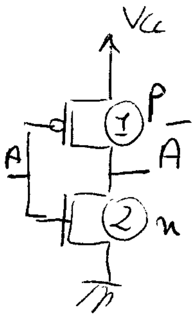
$$= (\overline{A+D})(\overline{CD} + B + \overline{E}) + \overline{BC}(A + \overline{D}E) + \overline{D}E =$$

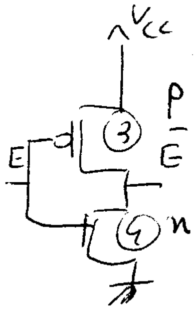
$$= \overline{A}\,\overline{D}(\overline{C}+\overline{D}+B+\overline{E}) + (\overline{B}+\overline{C})(A+\overline{D}E) + \overline{D}E =$$

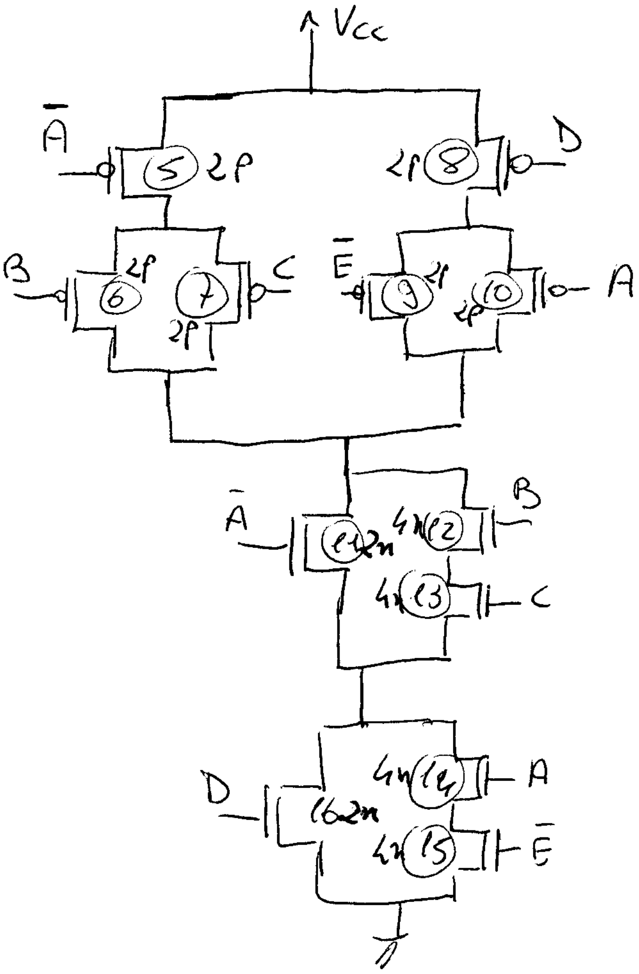
$$= \overline{A}\,\overline{C}\,\overline{D} + \overline{A}\,\overline{D} + \overline{A}B\overline{D} + \overline{A}\,\overline{D}\,\overline{E} + A\overline{B} + \overline{B}\,\overline{D}E + A\overline{C} + \overline{C}\,\overline{D}E + \overline{D}E =$$

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

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







$Q_1, Q_3 : p$

$Q_2, Q_4 : n$

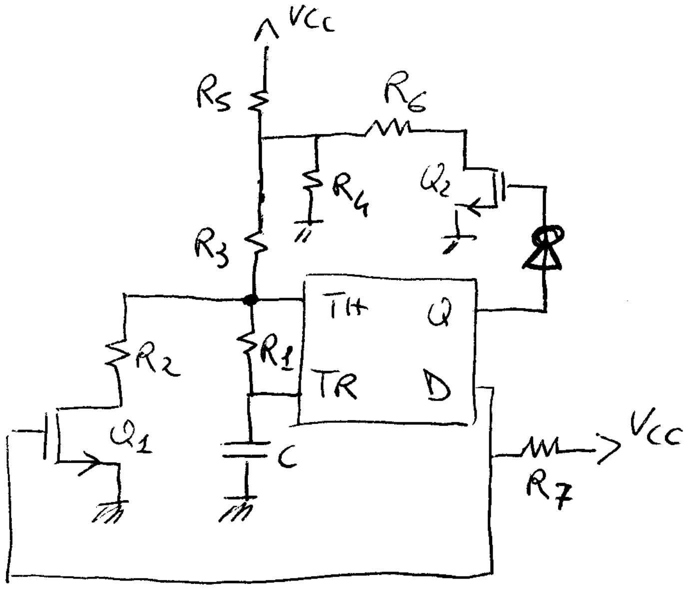
$Q_5, Q_6, Q_7, Q_8, Q_9, Q_{10} : 2p$

SERIE $Q_{12}, Q_{13}\ Q_{14}, Q_{15} \Rightarrow 4n$

SERIE Q_{12}, Q_{13}, Q_{16} : $\frac{1}{x_{16}} + \frac{2}{4n} = \frac{1}{n} \Rightarrow \frac{1}{x_{16}} = \frac{1}{2n} \Rightarrow x_{16} = 2n$ $\quad Q_{16} : 2n$

SERIE Q_{11}, Q_{16} : $\frac{1}{x_{11}} + \frac{1}{2n} = \frac{1}{n} \Rightarrow \frac{1}{x_{11}} = \frac{1}{2n} \Rightarrow x_{11} = 2n$ $\quad Q_{11} : 2n$

1210 C



$R_1 = 500\,\Omega$

$R_2 = 4\,k\Omega$

$R_3 = 300\,\Omega$

$R_4 = 1\,k\Omega$

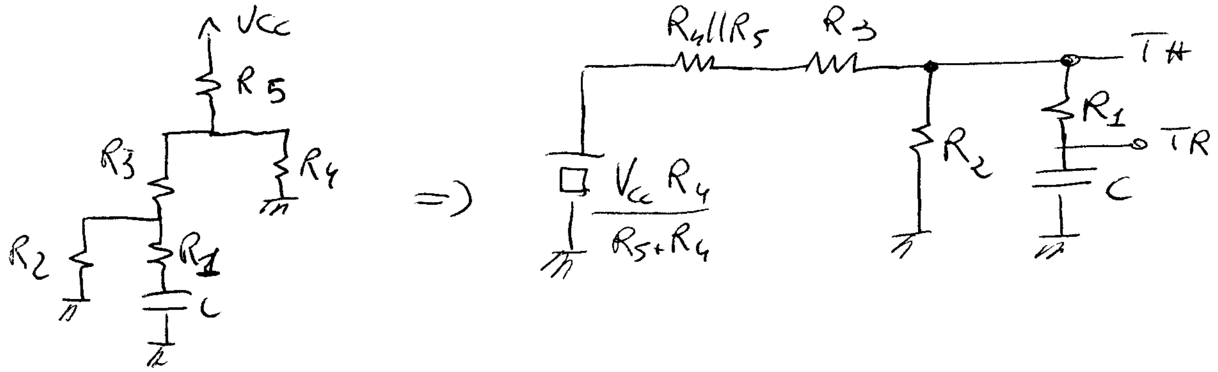
$R_5 = 100\,\Omega$

$R_6 = 10\,\Omega$

$R_7 = 1\,k\Omega$

$C = 680\,nF$

1) $Q = 1$ D: alta impedenza $\Rightarrow$ Q_1 ON, Q_2 OFF



$$V_i = \frac{1}{3} V_{cc} = 1.\overline{6}$$

$$V_f = \left(\frac{V_{cc} R_4}{R_5 + R_4} \right) \frac{1}{R_4 \| R_5 + R_3 + R_2} \cdot R_2 = 4.140786\ V$$

Per calcolar V_{cor} con $V_{TH} = \frac{2}{3} V_{cc}$

$$I_{R3} = \left(\frac{V_{cc} R_4}{R_5 + R_4} - \frac{2}{3} V_{cc} \right) \frac{1}{R_4 \| R_5 + R_3} = 3.100775 \times 10^{-3}\ A$$

$$V_i < V_{cor} < V_f$$

$$1.\overline{6}V < 2.1996V < 4.14\ V$$

$$I_{R2} = \frac{2}{3} V_{cc} \frac{1}{R_2} = 8.\overline{3} \times 10^{-4}\ A$$

$$I_{R1} = I_{R3} - I_{R2} = 2.26744 \times 10^{-3}\ A$$

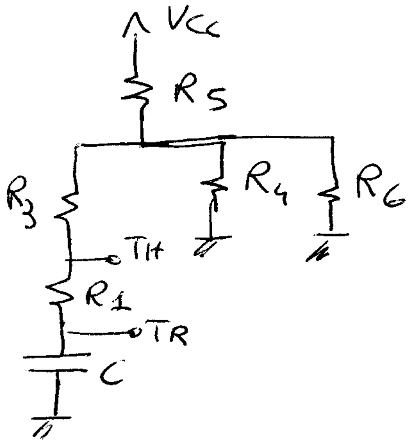
$$V_{cor_1} = \frac{2}{3} V_{cc} - R_1 I_{R1} = 2.1996\ V$$

$$R_{Vc} = R_1 + R_2 \| \left[R_3 + (R_4 \| R_5) \right] = 856.10766\ \Omega$$

$$\tau_1 = C R_{Vc} = 5.8215 \times 10^{-4}\ s = 0.58215\ ms$$

$$T_1 = \tau_1 \ln \frac{V_i - V_f}{V_{cor} - V_f} = 1.412218 \times 10^{-4}\ s = 0.14122\ ms$$

$\left.\begin{matrix} \ldots = 0 \\ \ldots = 0 \end{matrix}\right] \Rightarrow \begin{matrix} Q_1 \text{ OFF} \\ Q_2 \text{ ON} \end{matrix}$



$V_i = 2.1996\ V$

$V_{con} = \frac{1}{3} V_{cc} = 1.\overline{6}$

$V_f = \frac{V_{cc}}{R_5 + (R_4 \| R_6)} \cdot (R_4 \| R_6) = 0.\overline{450}\ V$

$R_{VC} = R_1 + R_3 + R_5 \| R_4 \| R_6 = 809.\overline{009}\ \Omega$

$\tau_2 = 5.50\overline{126} \times 10^{-4}\ s = 0.550126\ ms$

$T_2 = \tau_2 \ln \frac{V_i - V_f}{V_{con} - V_f} = 1.99907 \times 10^{-4}\ s = 0.1999\ ms$

$T = T_1 + T_2 = 3.41129 \times 10^{-4}\ s$

$f = \frac{1}{T} = 2931.4385\ Hz$

$V_i > V_{con} > V_f$

$2.1996V > 1.\bar{6}V > 0.4\bar{5}V$