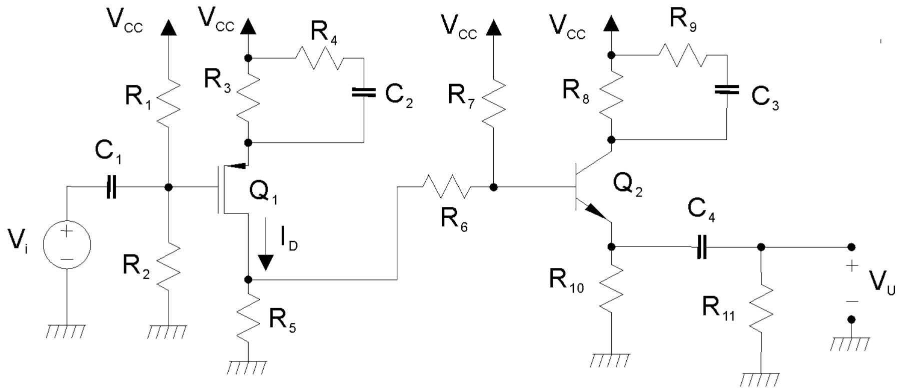
ELETTRONICA DIGITALE

Corso di Laurea in Ingegneria Informatica

Prova scritta 28 gennaio 2014

Esercizio A

R_1 =10 kΩ	R_{10} = 6 kΩ
R_2 = 20 kΩ	R_{11} = 20 kΩ
R_4 = 100 Ω	C_1= 10 nF
R_5 = 4 kΩ	C_2= 1 μF
R_6 = 20 kΩ	C_3 = 100 nF
R_7 = 265 kΩ	C_4 = 1 nF
R_8 = 500 Ω	V_{CC} = 18 V
R_9 = 1 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 = 1 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_3 in modo che, in condizioni di riposo, la tensione dell'emettitore di Q_2 sia 12 V. Determinare, inoltre, il punto di riposo dei due transistori e verificare la saturazione di Q_1. (R: R_3 = 1046.5 Ω)
2) Determinare 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 = - 9.58)
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} = 0 Hz; f_{p1} = 2387.32 Hz; f_{z2} = 138.82 Hz; f_{p2} = 492 Hz; f_{z4} = 0 Hz; f_{p4} = 7923 Hz)

Esercizio B

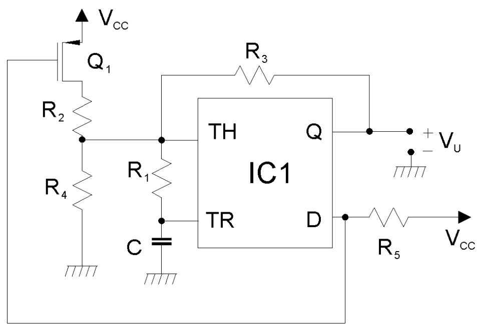
Progettare una porta logica in tecnologia CMOS, utilizzando la tecnica della pull-up network e della pull-down network, che implementi la funzione logica:

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

con in totale, non più di 18 transistori e disegnare 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 di tutti i transistori.

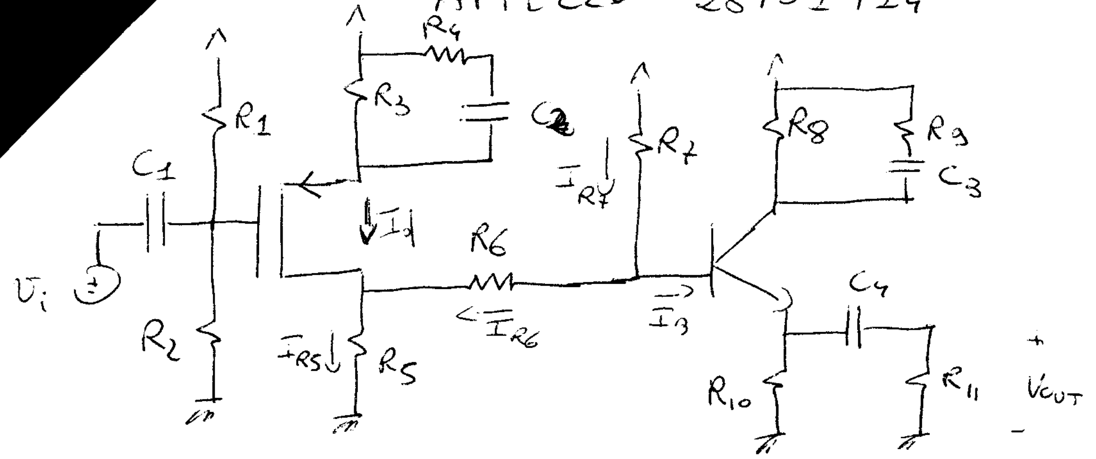
Esercizio C

R_1 =1 k Ω	R_4 = 4 k Ω
R_2 = 6 k Ω	R_5 = 1 k Ω
R_3 = 1 kΩ	C = 1 μF
V_{CC} = 5 V	



Il circuito IC_1 è un NE555 alimentato a V_{CC} = 5V, Q_1 ha una R_{on} = 0 e V_T = -1 V. Determinare la frequenza del segnale di uscita del multivibratore. (R: f = 564.4 Hz)

APPELLO 28/01/14



$R_1 = 10\,k\Omega$
$R_2 = 20\,k\Omega$
$R_4 = 100\,\Omega$
$R_5 = 4\,k\Omega$
$R_6 = 20\,k\Omega$
$R_7 = 265\,k\Omega$
$R_8 = 500\,\Omega$
$R_9 = 1\,k\Omega$
$R_{10} = 6\,k\Omega$
$R_{11} = 20\,k\Omega$
$C_1 = 10\,nF$ $\quad C_4 = 1\,nF$
$C_2 = 1\,\mu F$
$C_3 = 100\,nF$

$I_d = k\,(V_{GS} - V_T)^2$

$k = 1\ mA/V^2 \qquad V_T = -1V$

•) Det. R_3 per $V_E = 12V$

$I_E = \dfrac{V_E}{R_{10}} = 2\,mA$

$I_E \simeq I_C = 2mA$

$V_C = V_{CC} - R_8 I_C = 17\,V$

$V_{CE} = 17 - 12 = 5\,V$

$\Rightarrow$ $h_{FE} = 290$ $\quad \Rightarrow I_B = \dfrac{I_C}{h_{FE}} = 6.896\,\mu A$

$h_{ie} = 4800$

$h_{fe} = 300$

$V_B = V_E + V_\gamma = 12.7\,V$

$I_{R7} = \dfrac{V_{CC} - V_B}{R_7} = 20\,\mu A$

$I_{R6} = I_{R7} - I_B = 13.103\,\mu A$

$V_D = V_B - R_6 I_{R6} = 12.4379\,V$

$I_{RS} = \dfrac{V_D}{R_5} = 3.10348\ mA$

$I_D = I_{RS} - I_{R6} = 3.0364\ mA$

$(V_{GS} - V_T) = -\sqrt{\dfrac{I_D}{k}} = -1.7596\,V$

$V_{GS} = -2.7596\,V$

$V_G = \dfrac{V_{CC}\,R_2}{R_1 + R_2} = 12\,V$

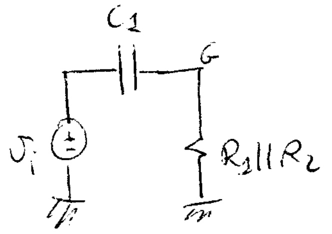
$V_S = V_G - V_{GS} = 14.7596$

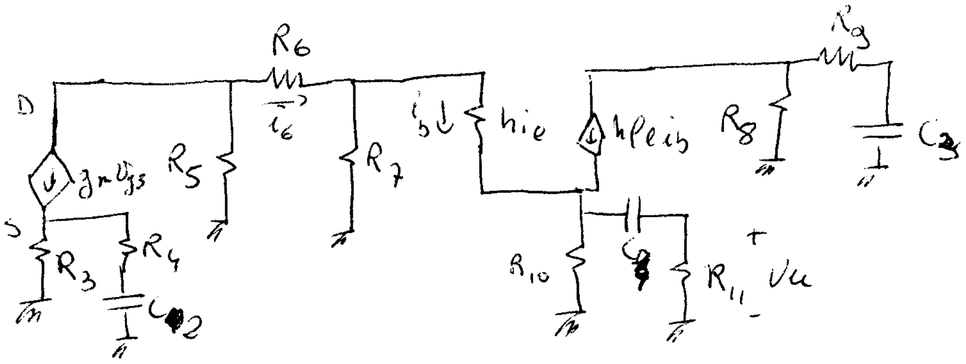
$\underline{\underline{R_3}} = \dfrac{V_{CC} - V_S}{I_D} = \underline{\underline{1046.503\ \Omega}}$

$V_{DS} = -2.3217 < (V_{GS} - V_T) = -1.7596$

$g_m = 2k\,|V_{GS} - V_T| =$

$= 3.5192 \times 10^{-3}\ \dfrac{A}{V}$





$h_{ie} = 4800$

$h_{fe} = 300$

$g_m = 3.5192 \times 10^{-3}\ A/V$

$R_{10} \| R_{11} = 4615.38\ \Omega$

·) A_{CB}

$$V_u = (R_{10} \| R_{11})(h_{fe}+1)\, i_b$$

$$i_b = i_6 \frac{R_7}{R_7 + h_{ie} + (R_{10}\|R_{11})(h_{fe}+1)}$$

$$i_6 = (-g_m v_{gs}) \frac{R_5}{R_5 + \left\{ R_6 + R_7 \| \left[h_{ie} + (R_{10}\|R_{11})(h_{fe}+1) \right] \right\}}$$

$$\left.\begin{aligned} v_g &= v_i \\ v_s &= (g_m v_{gs})(R_3\|R_4) \end{aligned}\right] \Rightarrow v_{gs} = v_i - (g_m v_{gs})(R_3\|R_4) = \frac{v_i}{1+(g_m)(R_3\|R_4)}$$

$$A_{CB} = \frac{V_u}{v_i} = \underbrace{(R_{10}\|R_{11})(h_{fe}+1)}_{4888.38}\underbrace{(-g_m) \frac{R_5}{R_5 + R_6 + \left\{ R_7 \| \left[h_{ie} + (R_{10}\|R_{11})(h_{fe}+1) \right] \right\}}}_{0.0162159} \cdot$$

$$\cdot \underbrace{\frac{R_7}{R_7 + h_{ie} + (R_{10}\|R_{11})(h_{fe}+1)}}_{0.1597318} \cdot \underbrace{\frac{1}{1+ g_m (R_3\|R_4)}}_{0.75687} = -3.5846 \quad \left(\begin{aligned} &|A_{CB}|_{dB} \\ &13.63\ dB \end{aligned} \right)$$

·) POLI E ZERI

$C_1 = 10\ nF$

$$C_1: \quad f_{P1} = \frac{1}{2\pi (R_1\|R_2) C_1} = 2387.324\ Hz$$

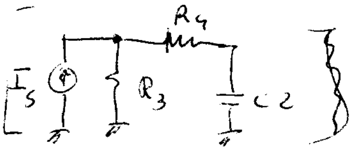
$$f_{Z1} = \phi\ Hz$$

$1\mu F$

$$R_{VC2} = R_4 + \left(R_3 \| \frac{1}{g_m}\right) = 323.4756\,\Omega$$

$$f_{P2} = \frac{1}{2\pi C_2 R_{VC2}} = 492.015\ Hz$$

$$f_{Z2} = \frac{1}{2\pi C_2 (R_4 + R_3)} = 138.817\ Hz$$



oppure $Z(s) = R_3 \| \left[R_4 + \frac{1}{Cs}\right] \to \infty$

C_3: polo e zero coincidenti

C_4 : $f_{Z4} = \phi$ $\qquad C_4 = 1nF$

$$R_{VC4} = R_{11} + \left\{R_{10} \| \left[\frac{((R_5 + R_6) \| R_7) + h_{ie}}{(h_{fe}+1)}\right]\right\} = 20087.752\ \Omega$$

$$f_{P4} = \frac{1}{2\pi C_4 R_{VC4}} = 7922.98\ Hz$$

$$\frac{V_u(s)}{V_i(s)} = A_{CB} \frac{s^2 (s + \omega_{z2})}{(s+\omega_{p1})(s+\omega_{p2})(s+\omega_{p4})}$$

$A_{CB} = -3.5846$

$\omega_{z2} = 872.21\ \frac{rad}{sec}$ ($f_{z2} = 138.817\ Hz$) $\qquad \omega_{p2} = 3091.42\ rad/sec$ ($f_{p2} =$ 492.015 Hz)

$\omega_{p1} = 14500\ \frac{rad}{s}$ ($f_{p1} = 2387.324\ Hz$) $\qquad \omega_{p4} = 49781.55\ rad/sec$ ($f_{p4} =$ 7922.98 Hz)

ESERCIZIO B

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

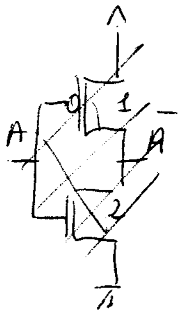
$$= (\bar{B} + \bar{C} + \bar{D}E + \bar{A})(C\bar{D}) + (\bar{B} + E)(C + \bar{E}) =$$

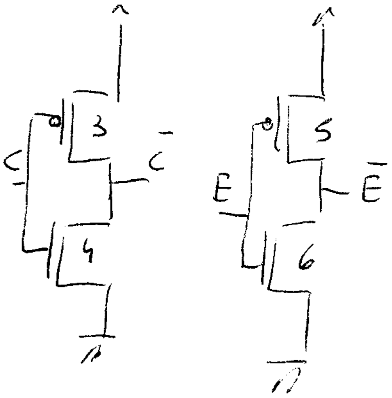
$$= \bar{B}C\bar{D} + \bar{C}C\bar{D} + CE\bar{D} + \bar{A}C\bar{D} + \bar{B}C + \bar{B}\bar{E} + EC + \cancel{E\bar{E}} =$$

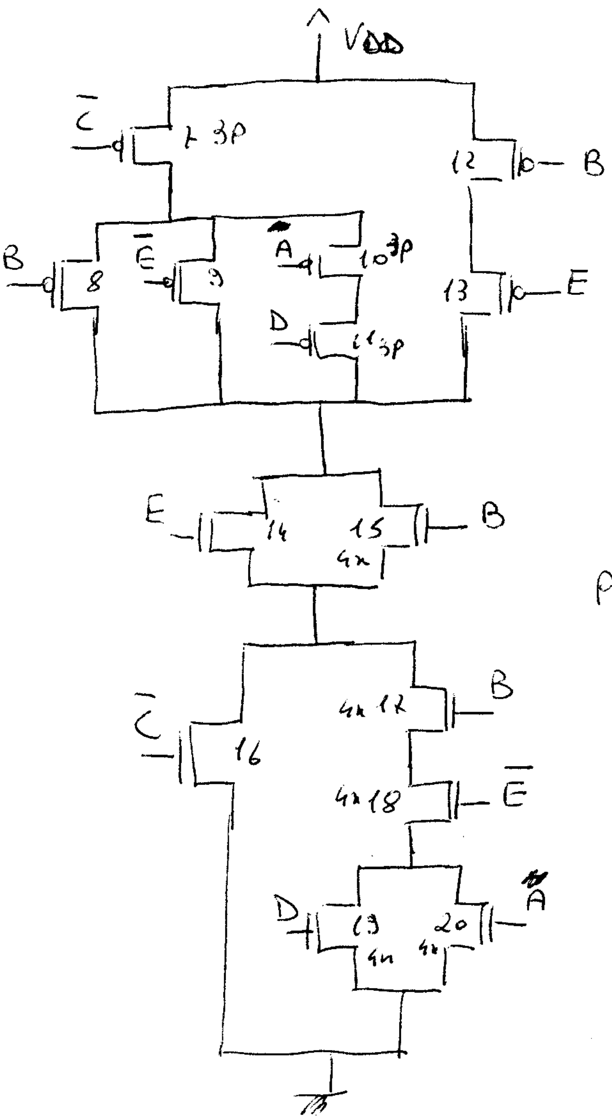
$$= \bar{B}C + CE + \bar{B}\bar{E} + \bar{A}C\bar{D} =$$

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

$\boxed{18 \text{ MOSFET}}$







Q_1, Q_3, Q_5 : p

Q_2, Q_4, Q_6 : n

PUN:

WORST CASE: Q_7, Q_{10}, Q_{11} : 3p

Q_8 pone Q_3 con Q_7

$\Rightarrow \frac{1}{x} + \frac{1}{3p} = \frac{1}{p} \Rightarrow x = \frac{3}{2}p = 1.5p$

Q_{12} e Q_{13} $\Rightarrow$ Q_{12}, Q_{13} : 2p

PDN:

WORST CASE

$Q_{15}, Q_{17}, Q_{18}, Q_{19}$

$Q_{15}, Q_{17}, Q_{18}, Q_{20}$

$\Rightarrow Q_{15}, Q_{17}, Q_{18}, Q_{19}, Q_{20} = 4n$

Per dim Q_{14} e Q_{16} due possibilità

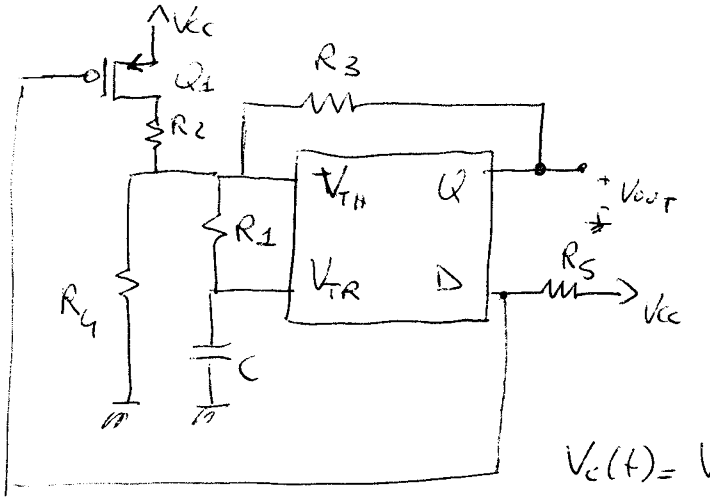
1) Q_{14} e Q_{16} da soli $\Rightarrow Q_{14}, Q_{16} : 2n$ $\Leftarrow$ SOLUZIONE AD AREA MINIMA

2) Q_{16} con Q_{15} $\Rightarrow Q_{16} \div \frac{1}{x} + \frac{1}{4n} = \frac{1}{n} \Rightarrow \left(\frac{W}{L}\right)_{16} = \frac{4}{3}n$

e Q_{14} con Q_{16} $\Rightarrow Q_{14} \div \frac{1}{x} + \frac{3}{4n} = \frac{1}{n} = \left(\frac{W}{L}\right)_{14} = 4n$

Con sol 1 Q_{15} e Q_{16} viene $\frac{1}{2n} + \frac{1}{4n} = \frac{3}{4n} \Rightarrow \left(\frac{W}{L}\right)_{eq} = \frac{4}{3}n > n$

ERCIZIO C

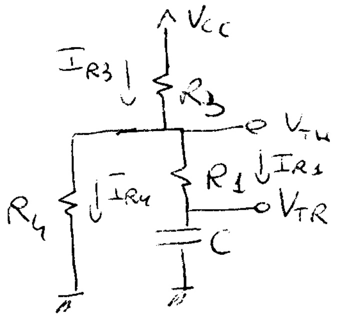


$R_1 = 1K\Omega$
$R_2 = 6K\Omega$
$R_3 = 1K\Omega$
$R_4 = 4K\Omega$
$C = 1\mu F$
$V_T = -1V$

$$V_C(t) = V_{FIN} + (V_{IN} - V_{FIN})\, e^{-\frac{t}{\tau}}$$

1) $Q = 1$

D alta impedenza $\Rightarrow$ $V_G = 5V$, $V_S = 5V$ $\Rightarrow$ $V_{GS} = \phi V > V_T$ $\Rightarrow$ Q_1 non conduce



$$V_{IN_1} = \frac{1}{3} V_{CC} = 1.\bar{6}$$

$$V_{FIN_1} = V_{CC} \frac{R_4}{R_3 + R_4} = 4V$$

$$V_{TH} = \frac{2}{3} V_{CC} \Rightarrow I_{R3} = \left(V_{CC} - \frac{2}{3} V_{CC}\right) \frac{1}{R_3} = 1.\bar{6}\ mA$$

$$I_{R4} = \left(\frac{2}{3} V_{CC}\right) \frac{1}{R_4} = 8.\bar{3} \times 10^{-4} A$$

$$I_{R1} = I_{R3} - I_{R4} = 8.\bar{3} \times 10^{-4} A$$

$$V_{COR_1} = \frac{2}{3} V_{CC} - I_{R1} R_1 = 2.5V$$

$V_{IN1} < V_{COR1} < V_{F1}$

$1.\bar{6}V < 2.5V < 4V$ ok

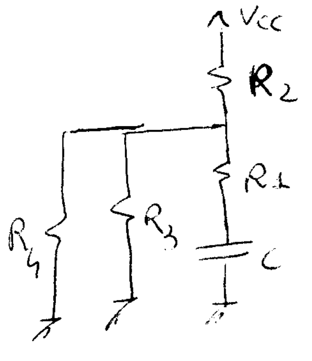
$$R_{VC_1} = R_1 + (R_3 \| R_4) = 1800\ \Omega$$

$$\tau_1 = 1.8\ ms$$

$$T_1 = \tau_1 \ln \frac{V_{IN_1} - V_{FIN_1}}{V_{COR_1} - V_{FIN_1}} = 7.953 \times 10^{-4}\ s$$

2) $Q = \phi$

$D = \phi \Rightarrow V_G = 0$ $V_S = 5V$ $V_{GS} = -5V < V_T$ $\Rightarrow$ Q ON



$$V_{IN2} = V_{COR1} = 2.5V$$

$$V_{COR2} = V_{IN1} = 1.\bar{6}\ V$$

$V_{IN2} > V_{COR2} > V_{F2}$

$2.5V > 1.\bar{6}V > 0.588V$

$$V_{FIN2} = V_{CC} \frac{R_3 \| R_4}{R_2 + R_3 \| R_4} = 0.588\ V$$

$$R_{VC_2} = R_1 + [R_3 \| R_4 \| R_2] = 1705.88\ \Omega$$

$\tau_2 = 1.70588$ ms

$$T_2 = \tau_2 \ln \frac{V_{IN_2} - V_{FIN_2}}{V_{COM2} - V_{FIN_2}} = 9.76487 \times 10^{-4}$$

$T = T_1 + T_2 = 1.77178$ ms

$$f = \frac{1}{T} = 564.40 \text{ Hz}$$