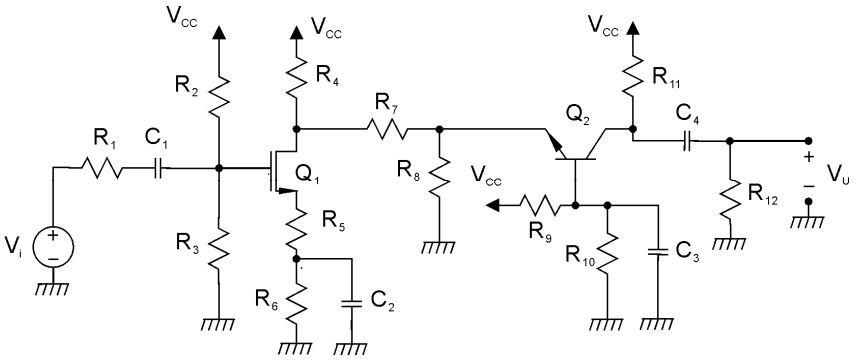
ELETTRONICA DIGITALE

Corso di Laurea in Ingegneria Informatica

Prova scritta del 16 febbraio 2016

Esercizio A

R_1 = 50 Ω	R_{11} =2.5 kΩ
R_3 = 100 kΩ	R_{12} = 20 kΩ
R_4 = 54.5 kΩ	C_1 = 220 pF
R_5 = 100 Ω	C_2 = 18 nF
R_6 = 1400 Ω	C_3= 15 nF
R_7 = 500 Ω	C_4= 6.8 nF
R_8 = 40 kΩ	V_{CC} = 18 V
R_9 =186 kΩ	



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 delle resistenze R_2 e R_{10} in modo che, in condizioni di riposo, la tensione sul drain di Q_1 sia 7.1 V e la tensione sull'emettitore di Q_2 sia 8 V. Determinare, inoltre, il punto di riposo dei due transistori e verificare la saturazione di Q_1. (R: R_2 = 200 kΩ, R_{10} = 201.84 kΩ)
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 = - 3.65)
3) (**Solo per 12 CFU**) Determinare la funzione di trasferimento V_U/V_i e tracciarne il diagramma di Bode quotato asintotico del modulo. (f_{z1}=0 Hz; f_{p1}=10843 Hz; f_{z2}=6316 Hz; f_{p2}=21052 Hz; f_{z3}=109.6 Hz; f_{p3}=111 Hz; f_{z4}=0 Hz; f_{p4}=1040 Hz;)

Esercizio B

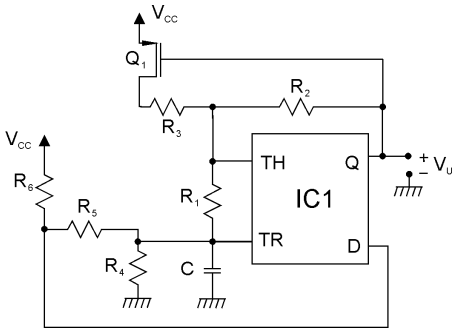
Progettare una porta logica in tecnologia CMOS, utilizzando la tecnica della pull-up network e della pull-down network, che implementi la funzione logica:

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

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.

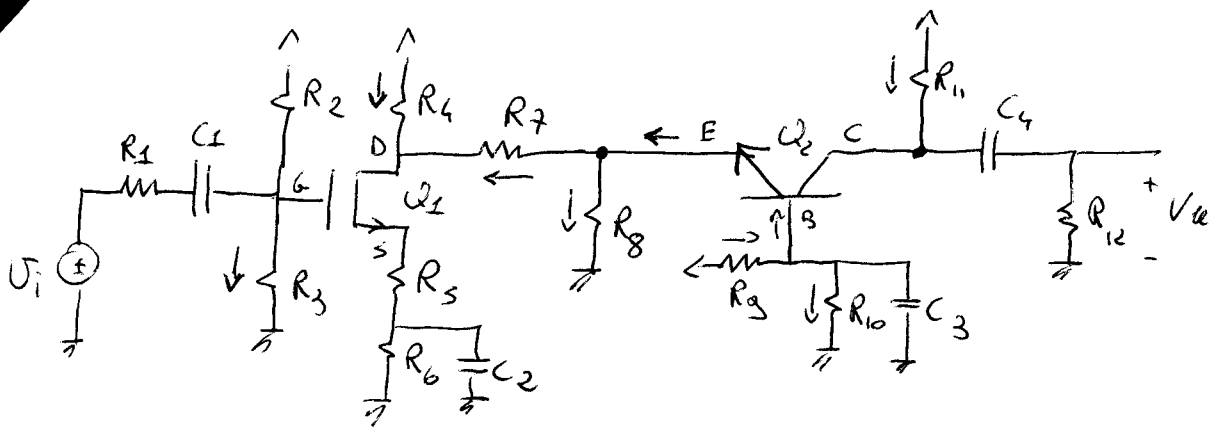
Esercizio C

R_1 = 1 kΩ	R_5 = 400 Ω
R_2 = 2 kΩ	R_6 = 200 Ω
R_3 = 10 kΩ	C = 22 nF
R_4 = 4.5 kΩ	**V_{CC} = 6 V**



Il circuito IC_1 è un NE555 alimentato a **V_{CC} = 6V**, Q_1 ha una R_{on} = 0 e V_T = -1V. Determinare la frequenza del segnale di uscita del multivibratore in figura. (R: f = 154339 Hz)

APPELLO 16/02/2016



$R_1 = 50\ \Omega$
$R_3 = 100\ k\Omega$
$R_4 = 54.5\ k\Omega$
$R_5 = 100\ \Omega$
$R_6 = 1400\ \Omega$
$R_7 = 500\ \Omega$
$R_8 = 40\ k\Omega$
$R_9 = 186\ k\Omega$
$R_{11} = 2.5\ k\Omega$
$R_{12} = 20\ k\Omega$
$C_1 = 220\ pF$
$C_2 = 18\ nF$
$C_3 = 15\ nF$
$C_4 = 6.8\ nF$
$V_{CC} = 18\ V$
$K = 0.5\ \frac{mA}{V^2}$

1) $V_D = 7.1\ V \qquad V_E = 8\ V$

$I_8 = \frac{V_E}{R_8} = 0.2\ mA$

$I_7 = \frac{V_E - V_D}{R_7} = \frac{0.9}{500} = 1.8\ mA$

$I_E = I_7 + I_8 = 2\ mA$

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

$V_C = V_{CC} - R_{11} I_C = 13\ V$

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

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

Q_2: $I_C = 2\ mA$, $V_{CE} = 5\ V$, $I_B = 6.896\ \mu A$, $h_{ie} = 4800\ \Omega$, $h_{fe} = 300$

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

$V_B = V_E + V_\gamma = 8.2\ V$

$I_9 = \frac{V_{CC} - V_B}{R_9} = 50\ \mu A$

$I_{10} = I_9 - I_B = 4.31 \times 10^{-5}\ A$

$R_{10} = \frac{V_B}{I_{10}} = 201840\ \Omega$

$I_4 = \frac{V_{CC} - V_D}{R_4} = 0.2\ mA$

$I_D = I_4 + I_7 = 2\ mA$

Q_1: $I_D = 2\ mA$, $V_{GS} = 3\ V$, $V_{DS} = 4.1\ V$, $g_m = 2\ \frac{mA}{V}$

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

perché NMOS $V_{GS} > V_T$

$V_S = (R_5 + R_6) I_D = 3\ V$

$V_{DS} = V_D - V_S = 4.1\ V$

$V_{DS} > (V_{GS} - V_T) = 2\ V \Rightarrow$ hp. SAT. OK

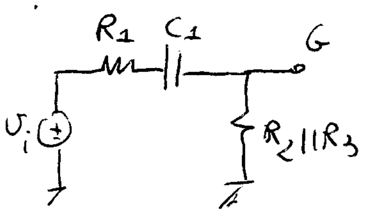
$\therefore V_{GS} + V_S = 3 + 3 = 6\,V$

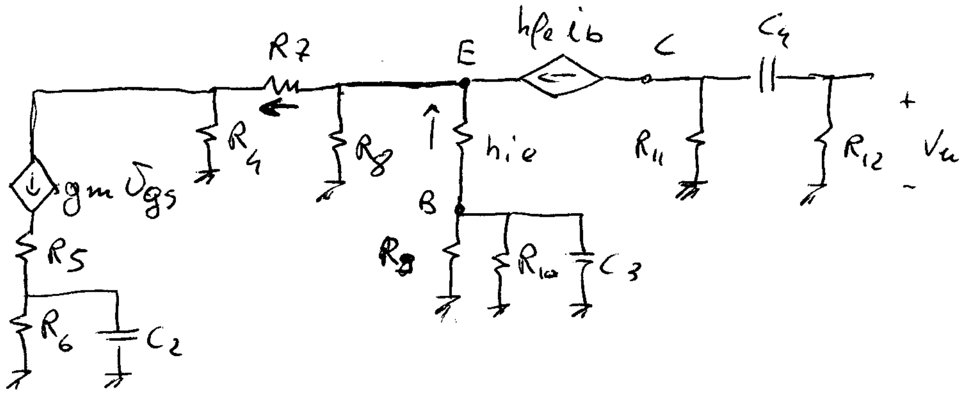
$I_3 = I_2 = \frac{V_G}{R_3} = 60\,\mu A$

$R_2 = \frac{V_{CC} - V_G}{I_2} = \frac{18-6}{60\times10^{-6}} = 200\,k\Omega$

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

2) A_{CB}





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

$(h_{fe}+1)\, i_b = i_7 \frac{R_8}{R_8 + \frac{h_{ie}}{h_{fe}+1}}$

$i_b = \frac{i_7}{(h_{fe}+1)} \frac{R_8(h_{fe}+1)}{R_8(h_{fe}+1) + h_{ie}} = i_7 \frac{R_8}{h_{ie} + R_8(h_{fe}+1)}$

$i_7 = g_m v_{gs} \frac{R_4}{R_4 + \left[R_7 + R_8 \| \frac{h_{ie}}{(h_{fe}+1)}\right]}$

$v_s = R_5\, g_m\, v_{gs}$

$v_{gs} = v_g - g_m R_5 v_{gs} = \frac{v_g}{1 + g_m R_5}$

$v_g = v_i \frac{R_2 \| R_3}{R_1 + R_2 \| R_3}$

$666666.\overline{6}$ | 3.32×10^{-3} | 2×10^{-3} | 0.9906 | $0.8\overline{3}$ | 0.9992

$$\frac{V_u}{V_i} = -h_{fe}(R_{11}\|R_{12}) \frac{R_8}{h_{ie} + R_8(h_{fe}+1)} \cdot g_m \frac{R_4}{R_4 + \left[R_7 + R_8 \| \frac{h_{ie}}{(h_{fe}+1)}\right]} \cdot \frac{1}{1 + g_m R_5} \cdot \frac{R_2\|R_3}{R_1 + R_2\|R_3} =$$

$= -3.65$

$\left|\frac{V_u}{V_i}\right|_{dB} = 11.25\,dB$

POLI E ZERI

C_1: $f_{z1} = \phi$ Hz

$$f_{p1} = \frac{1}{2\pi C_1 R_{v1}} = 10843.34 \text{ Hz}$$

$$R_{v1} = R_1 + R_2 \| R_3 = 66716.\bar{6}\ \Omega$$

C_2:

$$f_{z2} = \frac{1}{2\pi C_2 R_6} = 6315.67 \text{ Hz}$$

$$f_{p2} = \frac{1}{2\pi C_2 R_{v2}} = 21052.24 \text{ Hz}$$

$$R_{v2} = R_6 \| \left[R_5 + \frac{1}{g_m} \right] = 420\ \Omega$$

C_3:

$$f_{z3} = \frac{1}{2\pi C_3 (R_9 \| R_{10})} = 109.61 \text{ Hz}$$

$$f_{p3} = \frac{1}{2\pi C_3 R_{v3}} = 111.13 \text{ Hz}$$

~~$R_{v3} = R_9 \| R_{10} \| [\ldots]$~~

$$R_{v3} = R_9 \| R_{10} \| \left\{ h_{ie} + \left[(R_4 + R_7) \| R_8 \right] (h_{fe} + 1) \right\} = 95473.36\ \Omega$$

C_4:

$f_{z4} = \phi$ Hz

$$f_{p4} = \frac{1}{2\pi C_4 (R_{11} + R_{12})} = 1040.23 \text{ Hz}$$

ES B

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

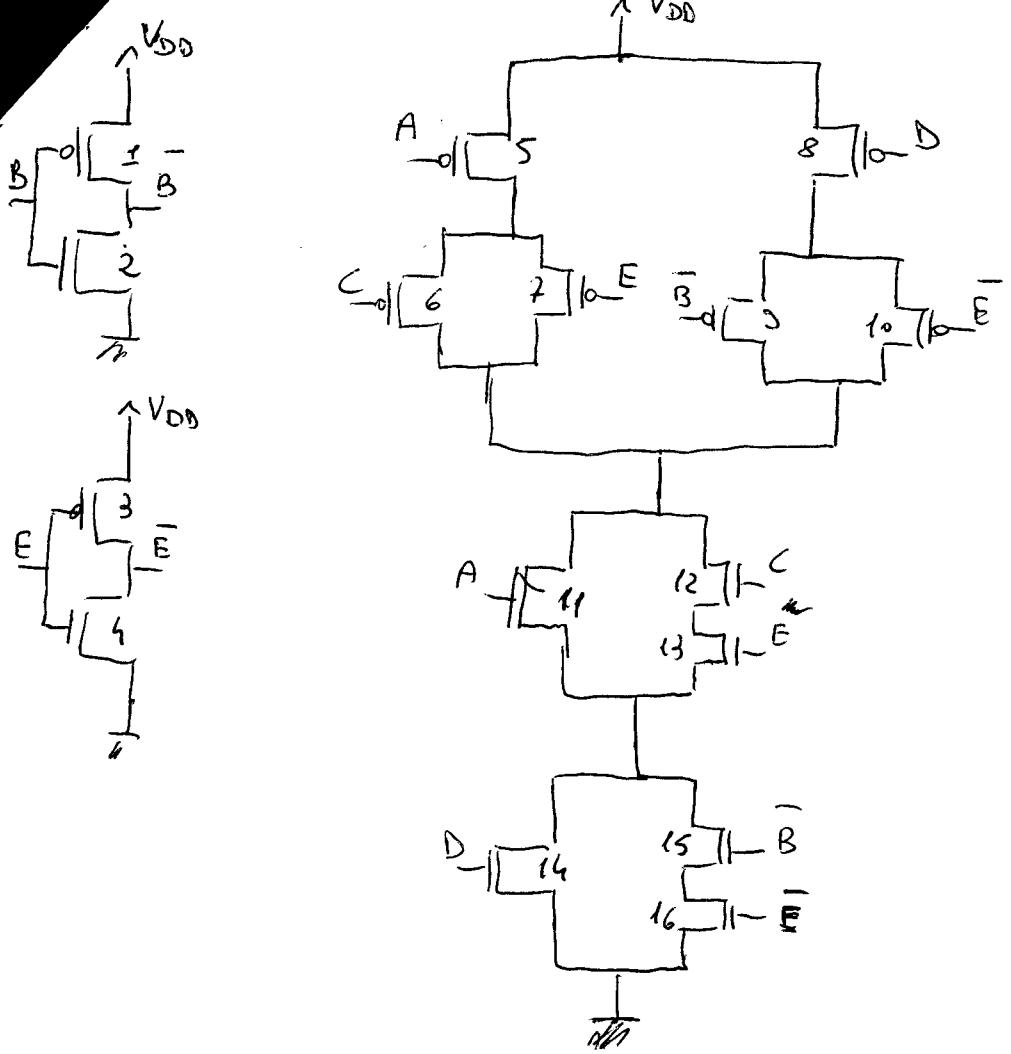
$$= \bar{A}B(\bar{C} + \bar{D} + \bar{E}) + \bar{A}\bar{B}\bar{C} + \bar{A}\bar{B}\bar{E} + AB\bar{D} + \bar{D}E =$$

$$= \underset{\times}{\bar{A}B\bar{C}} + \underset{\circ}{\bar{A}B\bar{D}} + \underset{\oplus}{\bar{A}B\bar{E}} + \underset{\times}{\bar{A}\bar{B}\bar{C}} + \underset{\oplus}{\bar{A}\bar{B}\bar{E}} + \underset{\circ}{AB\bar{D}} + \bar{D}E =$$

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

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

N MOS : 16 MOSFET



$$\left(\frac{W}{L}\right)_1 = \left(\frac{W}{L}\right)_3 = p = 5$$
$$\left(\frac{W}{L}\right)_2 = \left(\frac{W}{L}\right)_4 = n = 2$$
} INVERTER DI BASE

) PUN

Serie di 2 MOSFET $\quad \frac{1}{x} + \frac{1}{x} = \frac{1}{p} \Rightarrow x = 2p = 10$

$$\left(\frac{W}{L}\right)_{5,6,7,8,9,10} = 2p = 10$$

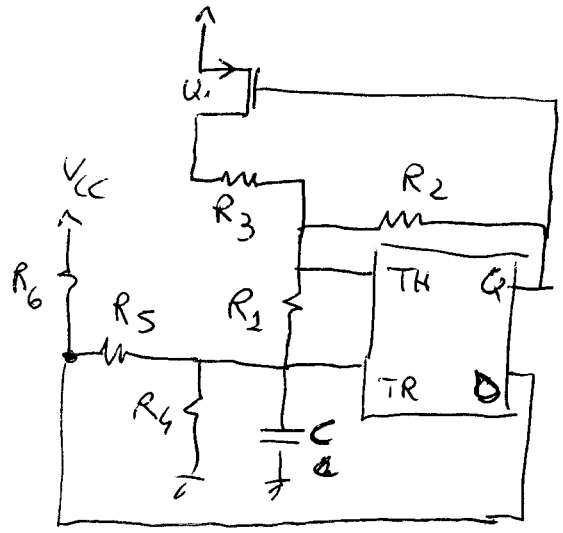
) PDN

Serie di 4 MOSFET non è possibile

Serie di 3 MOSFET: $Q_{11} - Q_{15} - Q_{16}$, $Q_{12} - Q_{13} - Q_{14}$ $\quad \frac{1}{x} + \frac{1}{x} + \frac{1}{x} = \frac{1}{n} \Rightarrow x = 3n = 6$

$$\left(\frac{W}{L}\right)_{11,12,13,14,15,16} = 3n = 6$$

ESERCIZIO C

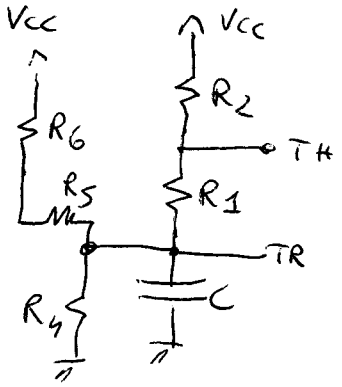


$R_1 = 1K\Omega$
$R_2 = 2K\Omega$
$R_3 = 10K\Omega$
$R_4 = 4.5K\Omega$
$R_5 = 400\Omega$
$R_6 = 200\Omega$
$C = 22nF$

1ª FASE

$Q = 1 \Rightarrow V_G = 6V \quad V_S = 6V \quad V_{GS} = 0V > V_T = -1V \Rightarrow Q_1$ OFF

$D = HI$



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

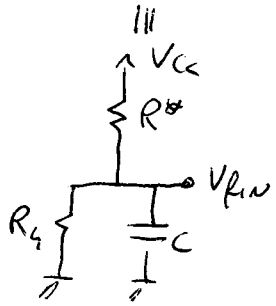
$R^* = (R_1 + R_2) \| (R_5 + R_6) = 500\Omega$

$V_{fin} = V_{CC} \frac{R_4}{R_4 + R^*} = 5.4V$

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

$I_{R2} = I_{R1} = \frac{V_{CC} - V_{TH}}{R_2} = 1mA$

$V_{com} = V_{TH} - R_1 I_{R1} = 3V$



$V_i < V_{com} < V_f \Rightarrow$ COMMUTA

$R_{VC_1} = R_4 \| R^* = 450\Omega$

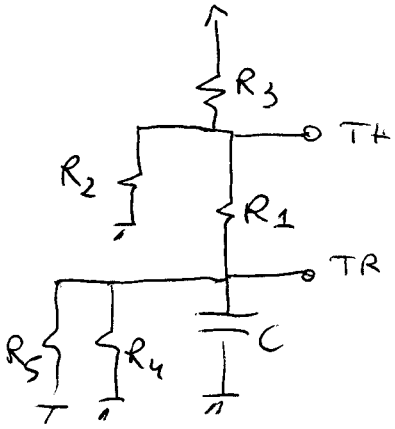
$\tau_1 = C R_{VC_1} = 9.9\mu s$

$T_1 = \tau_1 \ln\left(\frac{V_i - V_f}{V_{com} - V_f}\right) = 3.4482\mu s$

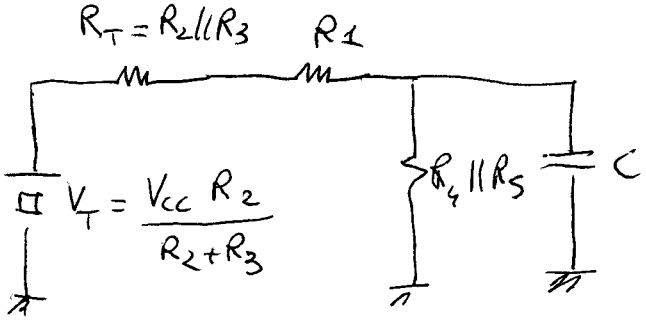
FASE

$Q = \phi \Rightarrow V_G = \phi \quad V_S = 6V \Rightarrow V_{GS} = -6V < V_T = -1V \Rightarrow Q_1$ ON

$D = \phi$



$\Rightarrow$



$V_i = 3V$; $V_{con} = 2V$

$$V_R = V_{cc} \frac{R_2}{R_2+R_3} \frac{1}{(R_2 \| R_3) + R_1 + (R_4 \| R_5)} \cdot (R_4 \| R_5) = 0.12107\ V$$

$$R_{VC2} = R_4 \| R_5 \| [R_1 + R_2 \| R_3] = 322.87\ \Omega$$

$$\tau_2 = R_{VC2} C = 7.103\ \mu s$$

$$T_2 = \tau_2 \ln\left(\frac{V_i - V_R}{V_{con} - V_R}\right) = 3.031\ \mu s$$

$$T = T_1 + T_2 = 6.479\ \mu s$$

$$f = \frac{1}{T} = 154338.59\ Hz$$