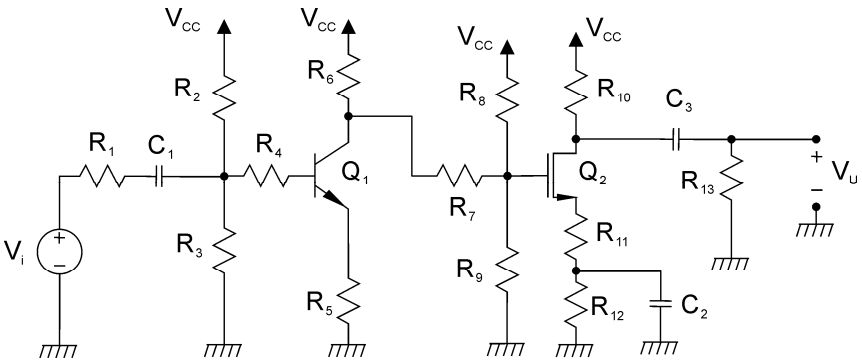
ELETTRONICA DIGITALE

Corso di Laurea in Ingegneria Informatica

Prova scritta del 27 gennaio 2015

Esercizio A

R_1 =100 Ω	R_{10} = 750 Ω
R_2 = 600 kΩ	R_{11} = 25 Ω
R_4 = 10 kΩ	R_{12} = 600 Ω
R_5 = 2 kΩ	R_{13} = 10 kΩ
R_6 = 6 kΩ	C_1 = 100 nF
R_7 = 2 kΩ	C_2 = 270 nF
R_8 = 8 kΩ	C_3= 1 nF
R_9 = 20 kΩ	V_{CC} = 18 V



Q_1 è un è un transistore BJT BC109B resistivo con $h_{re} = h_{oe} = 0$, Q_2 è 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.
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 = 314675.77 Ω)
2) Determinare V_U/Vi alle frequenze per le quali C_1, C_2, C_3 possono essere considerati dei corto circuiti. (R: V_U/Vi = 3.08)
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} = 10.284 Hz, f_{z2} = 982.44 Hz, f_{p2} = 3125.96 Hz, f_{z3} = 0 Hz, f_{p3} = 14805.11 Hz)

Esercizio B

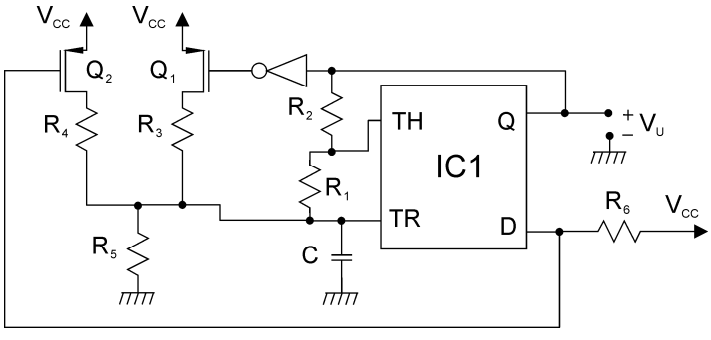
Progettare una porta logica in tecnologia CMOS, utilizzando la tecnica della pull-up network e della pull-down network, che implementi la funzione logica:

$$Y = \left(\overline{AB} + C\right)\left(\overline{C}\ \overline{D} + BE\right) + \left(\overline{C + \overline{D}}\right)\left(\overline{A} + \overline{B}\right) + ABE$$

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

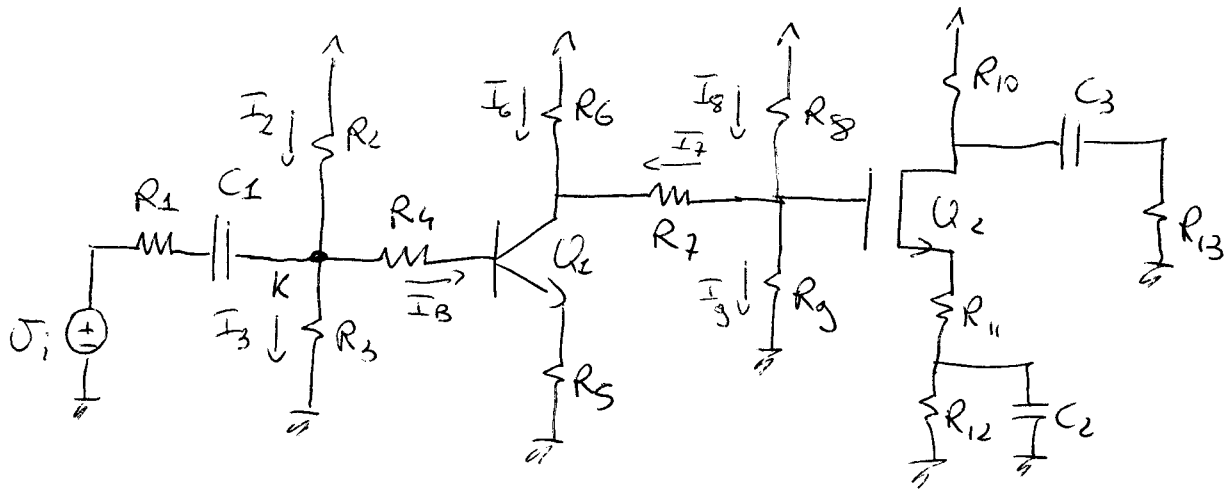
R_1 =400 Ω	R_5 = 4 kΩ
R_2 = 1600 Ω	R_6 = 1 kΩ
R_3 = 2 kΩ	C = 100 nF
R_4 = 4 kΩ	**V_{CC} = 6 V**



Il circuito IC_1 è un NE555 alimentato a **V_{CC} = 6V**, Q_1 e Q_2 hanno una R_{on} = 0 e V_T = -1V. Determinare la frequenza del segnale di uscita del multivibratore in figura. (R: f = 4999.75 Hz)

APPELLO 27/01/2015

ESERCIZIO A



$R_1 = 100\,\Omega$
$R_2 = 600\,K\Omega$
$R_4 = 10\,K\Omega$
$R_5 = 2\,K\Omega$
$R_6 = 6\,K\Omega$
$R_7 = 2\,K\Omega$
$R_8 = 8\,K\Omega$
$R_9 = 20\,K\Omega$
$R_{10} = 750\,\Omega$
$R_{11} = 25\,\Omega$
$R_{12} = 600\,\Omega$
$R_{13} = 10\,K\Omega$
$K = 0.5\ \frac{mA}{V^2}$
$V_{CC} = 18\,V$
$C_1 = 100\,nF$
$C_2 = 270\,nF$
~~$C_3 = 100\,nF$~~
$C_3 = 1\,nF$

1) Det. R_3 per $V_D = 12\,V$

$$I_{10} = \frac{V_{CC} - V_D}{R_{10}} = 8\,mA$$

$$V_S = I_{10}(R_{11} + R_{12}) = 5\,V$$

$$V_{GS} = V_T + \sqrt{\frac{I_{10}}{K}} = 1 + 4 = 5\,V$$

$$V_{DS} = 12 - 5 = 7\,V > (V_{GS} - V_T) = 4\,V$$

Q_2: $\begin{cases} I_D = 8\,mA \\ V_{DS} = 7\,V \\ V_{GS} = 5\,V \end{cases}$ $\quad g_m = 2K(V_{GS} - V_T) = 4 \times 10^{-3}\ \frac{A}{V}$

$$V_G = V_{GS} + V_S = 5 + 5 = 10\,V$$

$$I_8 = \frac{V_{CC} - V_G}{R_8} = 1\,mA$$

$$I_9 = \frac{V_G}{R_3} = 0.5\,mA$$

$$I_7 = I_8 - I_9 = 0.5\,mA$$

$$V_C = V_G - R_7 I_7 = 10 - 1 = 9\,V$$

$$I_6 = \frac{V_{CC} - V_C}{R_6} = \frac{9}{600} = 1.5\,mA$$

$$I_C = I_6 + I_7 = 2\,mA \simeq I_E$$

$$V_E = I_E R_5 = 4\,V$$

$$V_{CE} = V_C - V_E = 9 - 4 = 5\,V$$

$$\Rightarrow Q_1 \begin{cases} I_C = 2\,mA \\ V_{CE} = 5\,V \\ \beta_F = 290 = h_{FE} \\ h_{fe} = 300 \quad h_{ie} = 4800\,\Omega \end{cases}$$

$$\frac{I_C}{h_{FE}} = 6.836\ \mu A$$

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

$$V_K = V_B + R_4 I_B = 4.7689\ V$$

$$I_2 = \frac{V_{CC} - V_K}{R_2} = 22.05\ \mu A$$

$$I_3 = I_2 - I_B = 15.155\ \mu A$$

$$R_3 = \frac{V_K}{I_3} = 314675.768\ \Omega$$

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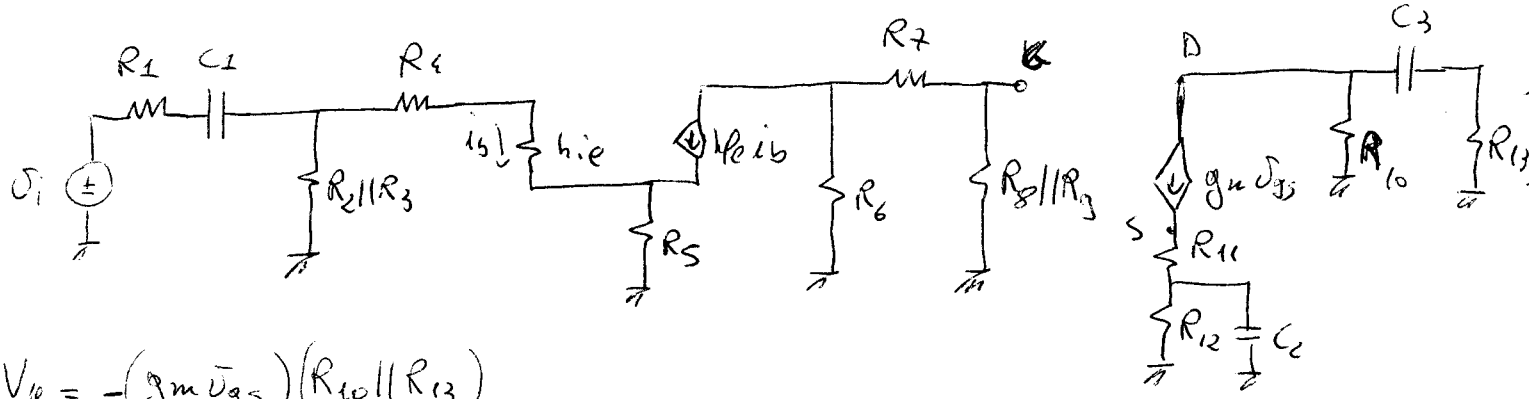
2) A_{CB}



$$V_{ic} = -(g_m \bar{v}_{gs})(R_{10} \| R_{13})$$

$$V_S = (g_m \bar{v}_{gs})\, R_{11}$$

$$\bar{v}_{gs} = \bar{v}_g - g_m \bar{v}_{gs} R_{11} \Rightarrow$$

$$\bar{v}_{gs} = \frac{\bar{v}_g}{1 + g_m R_{11}}$$

$$\bar{v}_g = -(h_{fe}\, i_b)\frac{R_6}{R_6 + R_7 + (R_8 \| R_9)} \cdot (R_8 \| R_9)$$

$$i_b = \frac{\bar{v}_i}{R_1 + R_2 \| R_3 \| \left[R_4 + h_{ie} + R_5(h_{fe}+1)\right]} \cdot \frac{R_2 \| R_3}{(R_2 \| R_3) + \left[R_4 + h_{ie} + R_5(h_{fe}+1)\right]}$$

2.537 $\quad 749999.\bar{9}$ $\quad 6.4616 \times 10^{-6}$

$$A_{CB} = \frac{V_{ic}}{V_i} = \underbrace{g_m \frac{R_{10} \| R_{13}}{1 + g_m R_{11}}}_{0.2507} \cdot \underbrace{\frac{h_{fe}\, R_6\, (R_8 \| R_9)}{R_6 + R_7 + R_8 \| R_9}}_{616800} \cdot \frac{1}{R_1 + R_2 \| R_3 \| \left[R_4 + h_{ie} + R_5(h_{fe}+1)\right]} \cdot \frac{R_2 \| R_3}{(R_2 \| R_3) + \left[R_4 + h_{ie} + R_5(h_{fe}+1)\right]} = 3.083 \quad (9.78\ dB)$$

f. d. t.

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

$$f_{p1} = \frac{1}{2\pi C_1 R_{v1}} = 10.284 \text{ Hz}$$

$$R_{v1} = R_1 + \left\{ R_2 \| R_3 \| \left[R_4 + hie + R_5 (hfe + 1) \right] \right\} = 154759.62 \ \Omega$$

C_2: $$f_{z2} = \frac{1}{2\pi C_2 R_{12}} = 982.44 \text{ Hz}$$

$$f_{p2} = \frac{1}{2\pi C_2 R_{v2}} = 3125.96 \text{ Hz}$$

$$R_{v2} = R_{12} \| \left[R_{11} + \frac{1}{gm} \right] = 188.57 \ \Omega$$

C_3: $f_{z3} = \phi$ Hz

$$f_{p3} = \frac{1}{2\pi C_3 R_{v3}} = 14805.11 \text{ Hz}$$

$$R_{v3} = R_{10} + R_{13} = 10750 \ \Omega$$

ESERCIZIO B

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

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

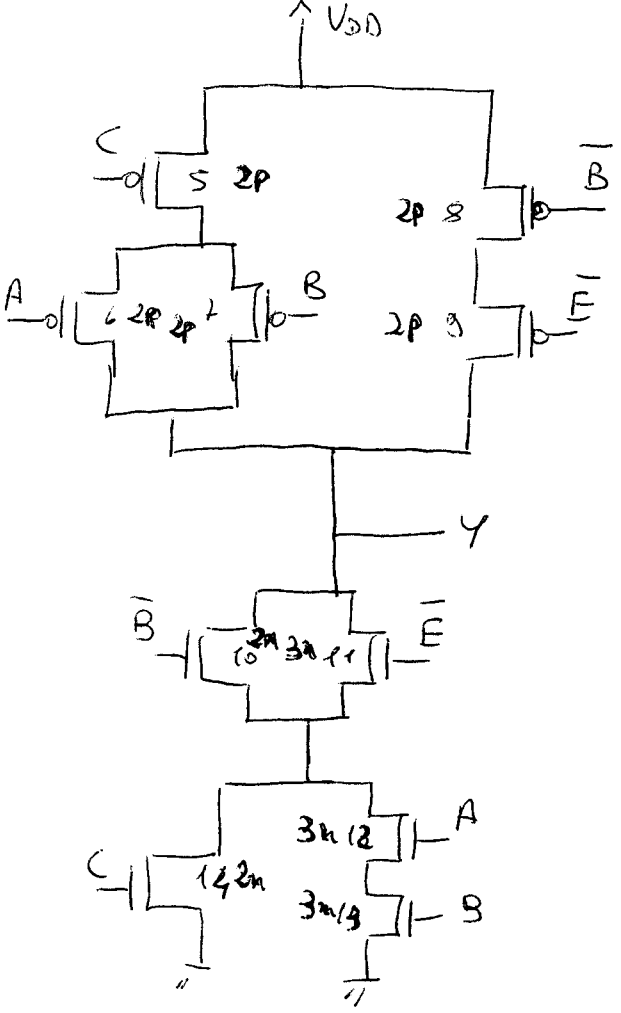
$$= \bar{A}\bar{C}\bar{D} + \bar{A}BE + \bar{B}\bar{C}\bar{D} + BCE + \bar{A}\bar{C}D + \bar{B}\bar{C}D + ABE =$$

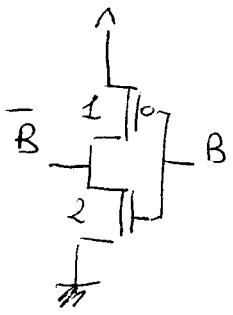
$$= \bar{A}\bar{C} + \bar{A}BE + \bar{B}\bar{C} + BCE + ABE =$$

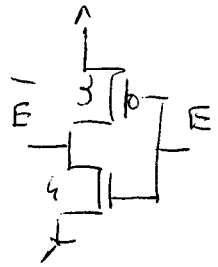
$$= \bar{A}\bar{C} + \bar{B}\bar{C} + BE =$$

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

Servono 14 MOSFET (5×2 + 4)







) INVERTER

$Q_1 = Q_3 : p = 5$

$Q_2 = Q_4 : n = 2$

) PUN

Q_5, Q_6
Q_5, Q_7
Q_8, Q_8

$\frac{2}{x} = \frac{1}{p} \Rightarrow x = 2p = 10 = \left(\frac{W}{L}\right)_{5,6,7,8,9}$

) PDN

Q_{11}, Q_{12}, Q_{13} : $\frac{3}{x} = \frac{1}{n} \Rightarrow x = 3n = 6 = \left(\frac{W}{L}\right)_{11,12,13}$

Per Q_{14} 2 possibilità

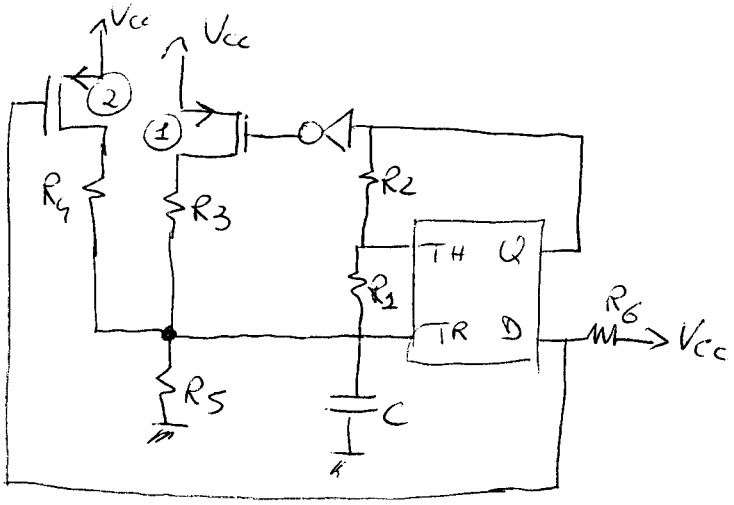
1 CASO: Q_{14}, Q_{11} $\frac{1}{x} + \frac{1}{3n} = \frac{1}{n} \Rightarrow x = \frac{3}{2}n = 3 = \left(\frac{W}{L}\right)_{14}$ $\left(\frac{W}{L}\right)_{14} + \left(\frac{W}{L}\right)_{10} = 9$

Da cui $\left(\frac{W}{L}\right)_{10} = 3n = 6$

2° CASO Q_{10}, Q_{14} $\frac{2}{x} = \frac{1}{n} \Rightarrow x = 2n = 4 = \left(\frac{W}{L}\right)_{10,14}$ SOLUZIONE AD AREA MINIMA

$\left(\frac{W}{L}\right)_{10} + \left(\frac{W}{L}\right)_{14} = 8$

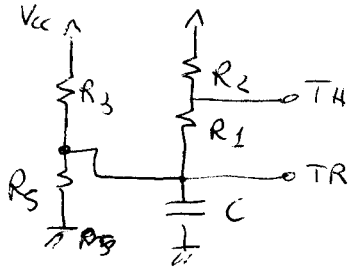
ERC1210 C



$V_{cc} = 6V$
$R_1 = 400\,\Omega$
$R_2 = 1600\,\Omega$
$R_3 = 2000\,\Omega$
$R_4 = 4K\Omega$
$R_5 = 4K\Omega$
$R_6 = 1K\Omega$
$C = 100\,nF$
$V_{T_{1,2}} = \pm 1V$

1° PERIODO

Q = 1 $V_{G1} = 0V$ $V_{S1} = 6V$ $\Rightarrow V_{GS1} = -6V < V_{T1} \Rightarrow Q_1$ ON
D = HI $V_{G2} = 6V$ $V_{S1} = 6V$ $\Rightarrow V_{GS1} = 0V > V_{T2} \Rightarrow Q_2$ OFF



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

$V_f = V_{cc}\,\frac{R_5}{R_5 + [R_3 \| (R_1+R_2)]} = 4.8V$

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

$I_{R1} = \frac{V_{cc} - \frac{2}{3}V_{cc}}{R_2} = 1.25\,mA$

$V_{con_1} = \frac{2}{3}V_{cc} - R_1 I_{R1} = 3.5V$

$V_i < V_{con} < V_f$
$2V < 3.5V < 4.8V$ OK

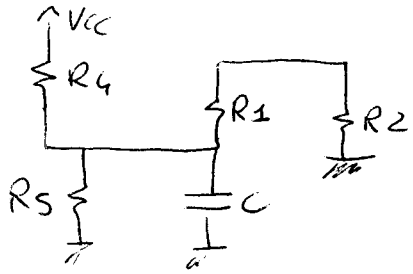
$R_{VC_1} = R_5 \| R_3 \| (R_1+R_2) = 800\,\Omega$

$\tau_1 = C R_{VC1} = 80\,\mu s$

$T_1 = \tau_1 \ln\left[\frac{V_i - V_f}{V_{con_1} - V_f}\right] = 6.138 \times 10^{-5}\,s = 61.38\,\mu s$

2° PERIODO

Q = 0 $V_{G1} = 6V$ $V_{S1} = 6V$ $\Rightarrow V_{GS1} = 0V \Rightarrow Q_1$ OFF
D = 0 $V_{G2} = 0V$ $V_{S2} = 6V$ $\Rightarrow V_{GS2} = -6V \Rightarrow Q_2$ ON



$= 3.5V$

$V_{corr2} = 2V$

$$V_{f2} = V_{cc} \frac{R_5 \| (R_1+R_2)}{[R_5 \| (R_1+R_2)] + R_4} = 1.5V$$

$V_i > V_{corr} > V_f$

$3.5V > 2V > 1.5V$ ok

$R_{V2} = R_5 \| R_4 \| (R_1+R_2) = 1K\Omega$

$\tau_2 = C_2 R_{V2} = 100\mu s$

$$T_2 = \tau_2 \ln\left[\frac{V_i - V_f}{V_{corr2} - V_f}\right] = 1.386 \times 10^{-4} s = 138.63\,\mu s$$

$T = T_1 + T_2 = 2 \times 10^{-4} s = 200\mu s$

$f = \frac{1}{T} = 4999.75\ Hz$