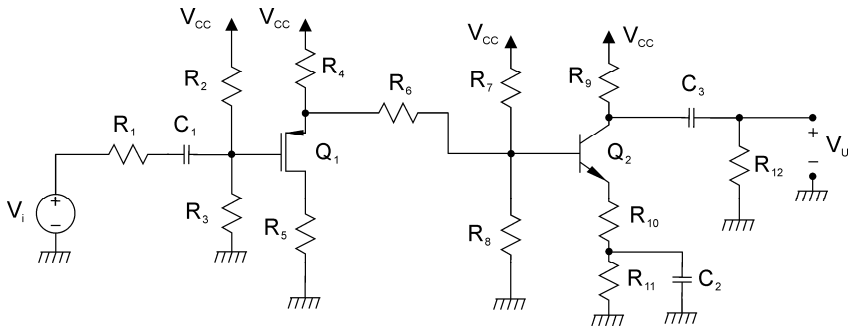
ELETTRONICA DIGITALE

Corso di Laurea in Ingegneria Informatica

Prova scritta del 09 gennaio 2015

Esercizio A

R_1 =100 Ω	R_{10} = 200 Ω
R_2 = 10 kΩ	R_{11} = 3.8 kΩ
R_4 = 1 kΩ	R_{12} = 10 kΩ
R_5 = 1 kΩ	C_1 = 10 nF
R_6 = 10 kΩ	C_2 = 47 nF
R_7 = 465 kΩ	C_3= 1 μF
R_8 = 20 kΩ	V_{CC} = 18 V
R_9 = 2.5 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_2è 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 sul collettore di Q_2 sia 13 V. Determinare, inoltre, il punto di riposo dei due transistori e verificare la saturazione di Q_1. (R: R_3 = 11847 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 = -4.359)
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} = 2881.79 Hz; f_{z2} = 891.12 Hz; f_{p2} = 15116.15 Hz; f_{z3} = 0 Hz; f_{p3} = 12.73 Hz)

Esercizio B

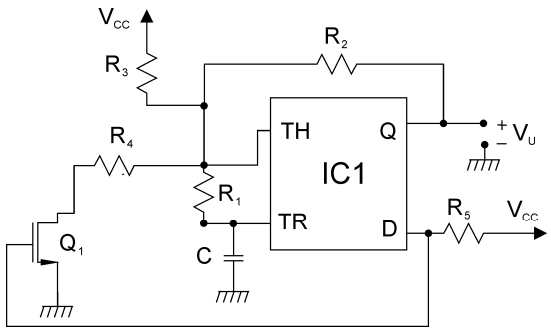
Progettare una porta logica in tecnologia CMOS, utilizzando la tecnica della pull-up network e della pull-down network, che implementi la funzione logica:

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

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

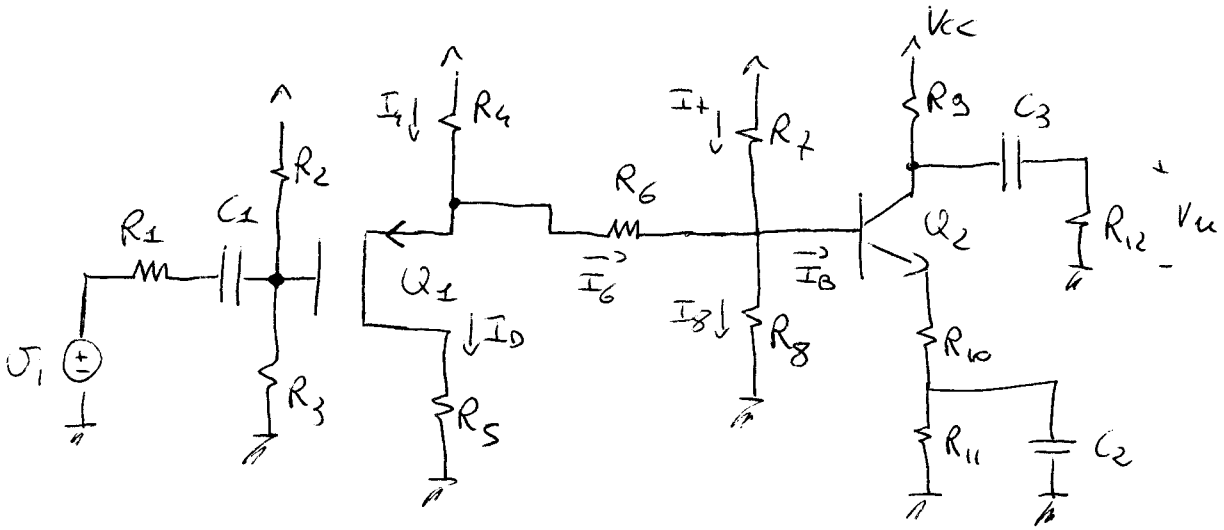
R_1 =50 Ω	R_5 = 1 kΩ
R_2 = 100 Ω	C = 1 μF
R_3 = 2 kΩ	**V_{CC} = 6 V**
R_4 = 1 kΩ	



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 = 7720 Hz)

COMPITO 09/01/2015

ESERCIZIO A



$V_{cc} = 18V$
$R_1 = 100\,\Omega$
$R_2 = 10K\Omega$
$R_4 = 1K\Omega$
$R_5 = 1K\Omega$
$R_6 = 10K\Omega$
$R_7 = 465K\Omega$
$R_8 = 20K\Omega$
$R_9 = 2.5K\Omega$
$R_{10} = 200\,\Omega$
$R_{11} = 3800\,\Omega$
$R_{12} = 10K\Omega$

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

$K = 1\,\frac{mA}{V^2}$

$C_1 = 10nF$
$C_2 = 47nF$
$C_3 = 1\mu F$

1) Det. R_3 per $V_C = 13V$

$$I_3 = \frac{V_{cc} - V_C}{R_3} = \frac{18-13}{250} = 2\,mA$$

$I_3 = I_C \simeq I_E$

$V_E = I_3(R_{10} + R_{11}) = 8V$

$$\begin{cases} V_{CE} = 13 - 8 = 5V \\ I_C = 2\,mA \\ \beta_F = 290 \end{cases} \Rightarrow I_B = \frac{I_C}{\beta_F} = 6.896\,\mu A$$

$V_B = V_E + V_\gamma = 8.7V$

$I_7 = \frac{V_{cc} - V_B}{R_7} = 20\,\mu A$

$I_8 = \frac{V_B}{R_8} = 435\,\mu A$

$I_6 = I_8 + I_B - I_7 = 421.896\,\mu A$

$V_S = V_B + R_6 I_6 = 12.919\,V$

$I_4 = \frac{V_{cc} - V_S}{R_4} = 5.081\,mA$

$I_D = I_S = I_4 - I_6 = 4.659\,mA$

$(V_{GS} - V_T) = -\sqrt{\frac{I_D}{K}} = -2.158\,V$

$V_{GS} = -3.158\,V$

$R_S \cdot I_D = 4.659\ V$

$$\begin{cases} V_{DS} = -8.26\ V \\ V_{GS} = -3.158\ V \end{cases} \Rightarrow V_{DS} < V_{GS} - V_T = -2.158\ V$$

$$g_m = 2K\,|V_{GS} - V_T| = 4.316 \times 10^{-3}\ \frac{A}{V}$$

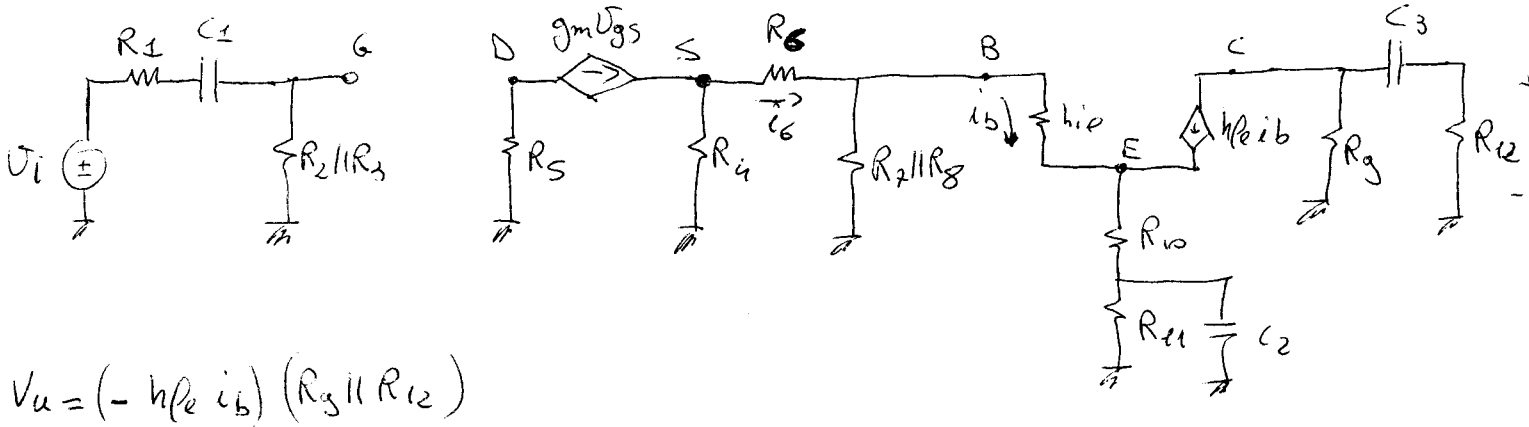
$V_G = V_{GS} + V_S = 9.761\ V$

$I_2 = I_3 = \dfrac{V_{CC} - V_G}{R_2} = 823.9\ \mu A$

$R_3 = \dfrac{V_G}{I_3} = 11847.31\ \Omega$

---

2) AMPLIFICAZIONE A_{CB}



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

$$i_G = (g_m V_{gs})\,\frac{R_4}{R_4 + \left\{R_6 + R_7 \| R_8 \| \left[h_{ie} + R_{10}(h_{fe}+1)\right]\right\}}$$

$$i_b = i_G\,\frac{R_7 \| R_8}{(R_7 \| R_8) + \left[h_{ie} + R_{10}(h_{fe}+1)\right]}$$

$$V_S = (g_m V_{gs})\,\underbrace{\left\{R_4 \| \left[R_6 + R_7 \| R_8 \| \left[h_{ie} + R_{10}(h_{fe}+1)\right]\right]\right\}}_{R^* = 961.25\ \Omega} = \ldots\,(g_m V_{gs})\,R^*$$

$$V_g = V_i\,\frac{R_2 \| R_3}{R_1 + (R_2 \| R_3)}$$

$$V_{gs} = V_i\,\frac{R_2 \| R_3}{R_1 + (R_2 \| R_3)} - (g_m V_{gs})\,R^*$$

$$V_{gs} = \frac{1}{1 + g_m R^*} \; V_i \; \frac{R_2 \| R_3}{R_1 + R_2 \| R_3}$$

$$A_{CB} = \frac{V_u}{V_i} = \underbrace{-h_{fe}\,(R_9 \| R_{12})\,g_m}_{502.956} \; \underbrace{\frac{1}{1 + g_m R^*}}_{0.982} \; \frac{R_2 \| R_3}{R_1 + R_2 \| R_3} \cdot \underbrace{\frac{R_4}{R_4 + \left\{ R_6 + R_7 \| R_8 \| \left[h_{ie} + R_{10}(h_{fe}+1) \right] \right\}}}_{3.8743 \times 10^{-2}}$$

$$\cdot \underbrace{\frac{R_7 \| R_8}{(R_7 \| R_8) + h_{ie} + R_{10}(h_{fe}+1)}}_{0.2278} = -4.359 \qquad \left(|A_{CB}|_{dB} = 12.79 \text{ dB} \right)$$

---

3) POLI E ZERI

.) C_1

$$f_{z1} = \phi$$

$$f_{p1} = \frac{1}{2\pi C_1 R_{vc1}} = 2881.29 \text{ Hz}$$

$$R_{vc1} = R_1 + R_2 \| R_3 = 5522.78 \; \Omega$$

.) C_2

$$f_{z2} = \frac{1}{2\pi C_2 R_{11}} = 891.135 \text{ Hz}$$

$$f_{p2} = \frac{1}{2\pi C_2 R_{vc2}} = 15116.15 \text{ Hz}$$

$$R_{vc2} = R_{11} \| \left\{ R_{10} + \frac{\left[\left(\frac{1}{g_m} \| R_4 \right) + R_6 \right] \| R_7 \| R_8 + h_{ie}}{(h_{fe}+1)} \right\} = 224.017 \; \Omega$$

.) C_3

$$f_{z3} = \phi$$

$$f_{p3} = \frac{1}{2\pi C_3 \underbrace{(R_9 + R_{12})}_{1250 \Omega}} = 12.73 \text{ Hz}$$

ESERCIZIO B

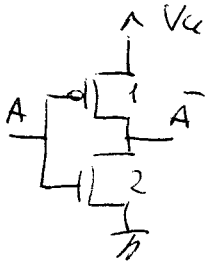
$$= \overline{(\bar{A}+C)}(\bar{C}D+\bar{D}E) + \overline{(D+\bar{E})}(A+B\bar{C}) + B\bar{C} + \bar{D}E =$$

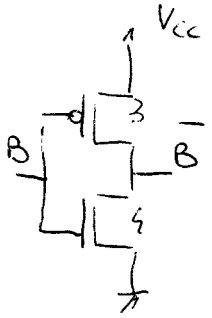
$$= (A\bar{C})(\bar{C}D+\bar{D}E) + \bar{D}E(A+B\bar{C}) + B\bar{C} + \bar{D}E =$$

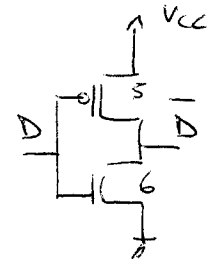
$$= A\bar{C}D + A\bar{C}\bar{D}E + A\bar{D}E + B\bar{C}\bar{D}E + B\bar{C} + \bar{D}E =$$

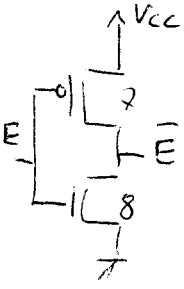
$$= A\bar{C}D + B\bar{C} + \bar{D}E =$$

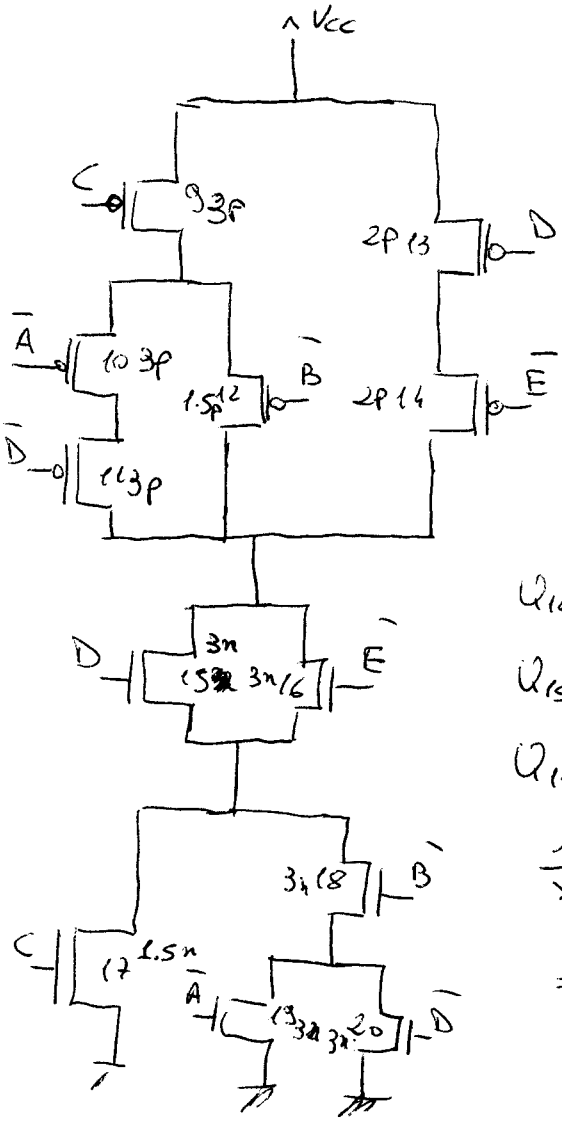
$$= \bar{C}(AD+B) + \bar{D}E \quad \Rightarrow \quad 20 \text{ MOSFET}$$











Q_1, Q_3, Q_5, Q_7 : p

Q_2, Q_4, Q_6, Q_8 : n

Q_9, Q_{10}, Q_{11} : 3p

Q_{13}, Q_{14} : 2p

$$\frac{1}{X_{12}} + \frac{1}{3p} = \frac{1}{p}$$

$$\frac{1}{X_{12}} = \frac{2}{3}\frac{1}{p} \Rightarrow X_{12} = \frac{3}{2}p = 1.5p$$

$Q_{16}, Q_{18}, Q_{19}, Q_{20}$ = 3n

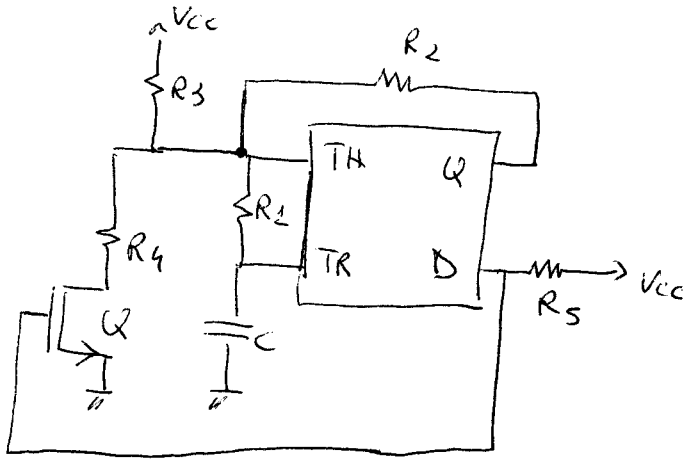
Q_{15} conduce con Q_{18}, Q_{19} => 3n

Q_{17} conduce con Q_{15} e Q_{16}

$$\frac{1}{X_{17}} + \frac{1}{3n} = \frac{1}{n}$$

$$\Rightarrow Q_{17} = \frac{3}{2}n = 1.5n$$

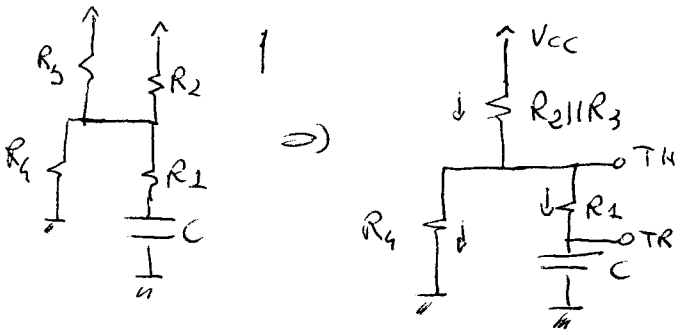
R1 R2 10 C



$V_{cc} = 6V$
$R_1 = 50\,\Omega$
$R_2 = 100\,\Omega$
$R_3 = 2\,K\Omega$
$R_4 = 1\,K\Omega$
$R_5 = 1\,K\Omega$
$C = 1\,\mu F$

1) $Q = 1$

$D = HI \Rightarrow V_G = V_{cc} \quad V_S = \phi \Rightarrow V_{GS} = 6V > V_T \Rightarrow Q$ ON



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

$V_f = V_{cc} \frac{R_4}{R_4 + R_2 \| R_3} = 5.428\ V$

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

$I_{R_2 \| R_3} = \frac{V_{cc} - V_{TH}}{R_2 \| R_3} = 2\,mA$

$I_{R_4} = \frac{V_{TH}}{R_4} = 4\,mA$

$I_{R_1} = I_{R_2 \| R_3} - I_{R_4} = 17\,mA$

$V_{con} = V_{TH} - I_{R_1} R_1 = 3.15\ V$

$V_i < V_{con_1} < V_{f_1}$

$2V < 3.15V < 5.428V$ OK

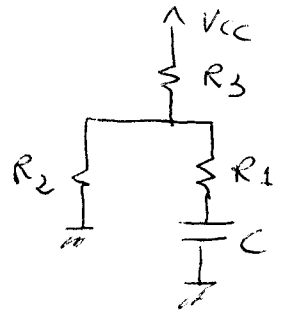
$R_{Vc} = R_1 + [R_2 \| R_3 \| R_4] = 136.9565\ \Omega$

$\tau_1 = C R_{Vc} = 1.36956 \times 10^{-4}\ s$

$T_1 = \tau_1 \ln \left[\frac{V_i - V_f}{V_{con} - V_f} \right] = 5.498 \times 10^{-5}\ s$

2) $Q = \phi$

$D = \phi \Rightarrow V_G = \phi \quad V_S = \phi \quad V_{GS} = 0 < V_T \Rightarrow Q$ OFF



$V_i = 3.15\ V$

$V_{con} = 2V$

$V_f = V_{cc} \frac{R_2}{R_2 + R_3} = 0.2857\ V$

$R_{V2} = R_1 + R_2 \| R_3 = 145.238\ \Omega$

$V_{i2} > V_{con2} > V_{f2}$

$3.15V > 2V > 0.2852V$

$\tau_2 = C R_{V2} = 1.452 \times 10^{-4} s$

$T_2 = \tau_2 \ln\left(\frac{V_i - V_f}{V_{con} - V_f}\right) = 7.455 \times 10^{-5} s$

$T = T_1 + T_2 = 1.295 \times 10^{-4} s$

$f = \frac{1}{T} = 7719.96\ Hz$