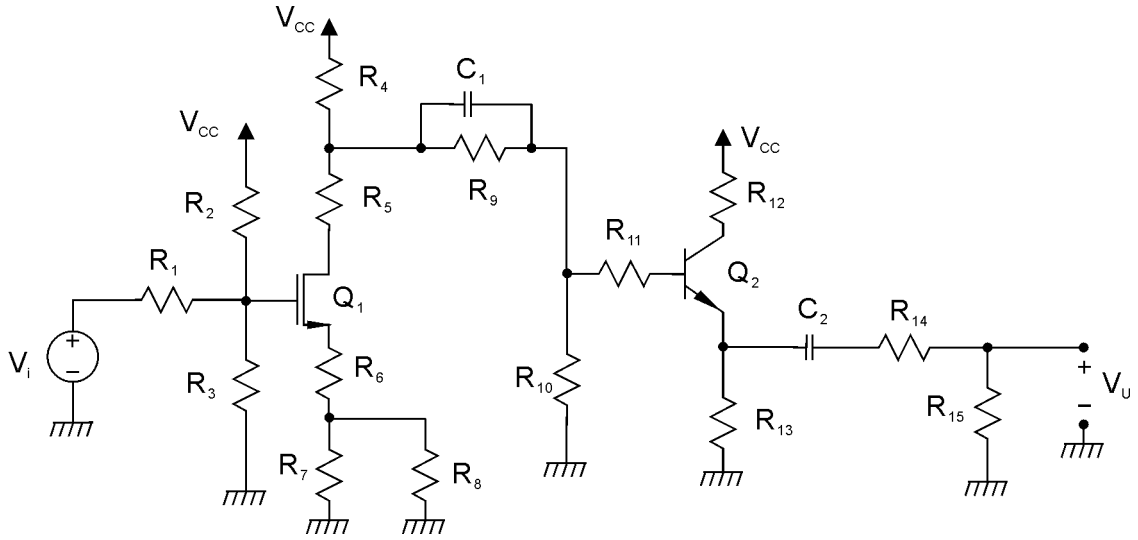
ELETTRONICA DIGITALE

Corso di Laurea in Ingegneria Informatica

Prova scritta del 17 settembre 2020

Esercizio 1



Q_1 è un transistore MOS a canale n resistivo con la corrente di drain in saturazione data da $I_D=k(V_{GS}-V_T)^2$; Q_2 è un transistore BJT BC109B resistivo con $h_{re} = h_{oe}= 0$.

Con riferimento al circuito in figura:

1) Determinare l'espressione di V_U/Vi alle frequenze per le quali i condensatori C_1 e C_2 possono essere considerati dei corto circuiti.

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Esercizio 2

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

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

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 di tutti i transistori.

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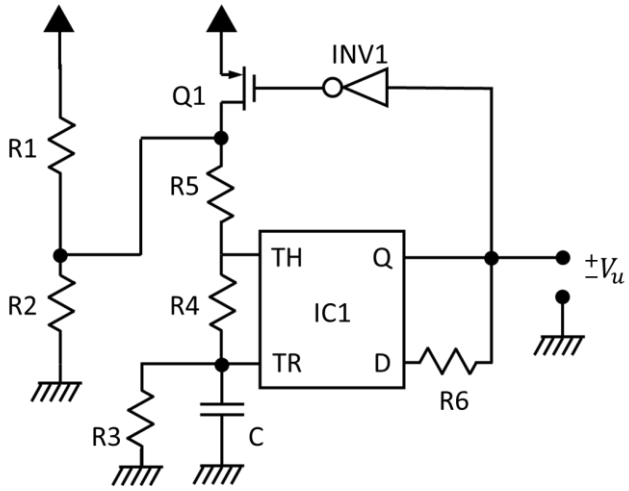
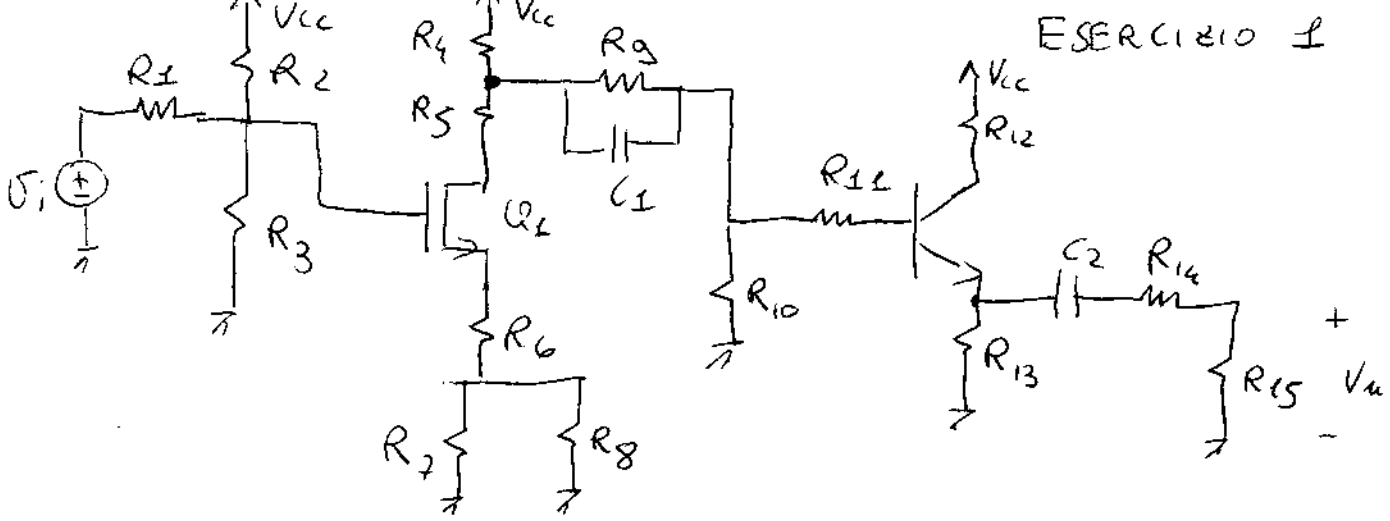
Esercizio 3

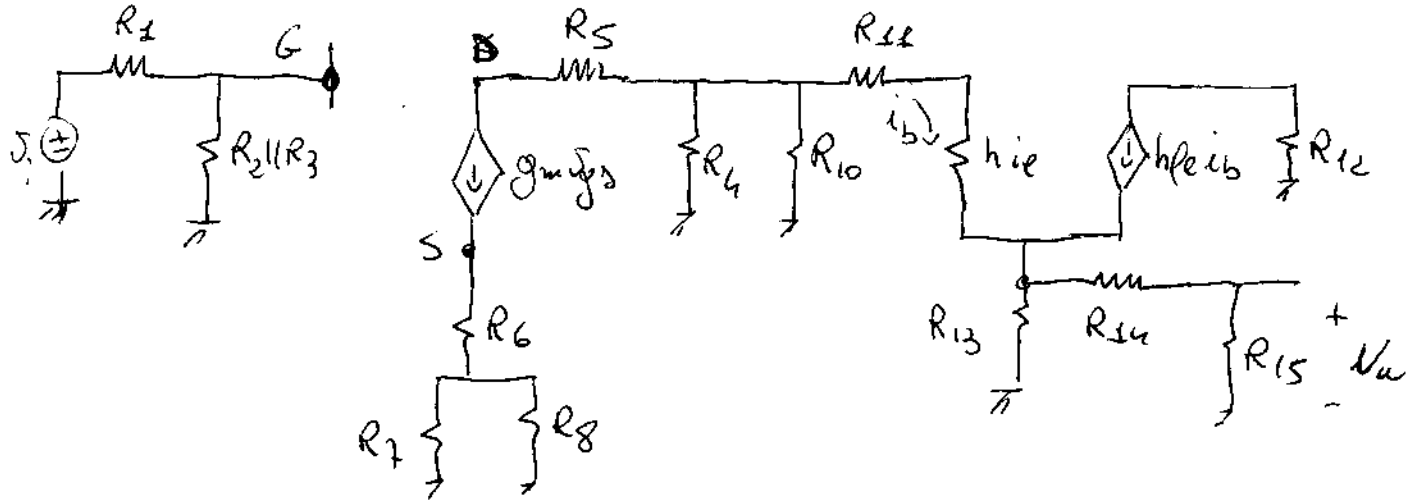
R1 = 10 kΩ	R5 = 1.5 kΩ
R2 = 2 kΩ	R6 = 1 kΩ
R3 = 5 kΩ	C = 1 µF
R4 = 500 Ω	VCC = 6 V



Il circuito IC1 è un NE555 alimentato a VCC = 6 V; Q1 ha una Ron = 0 e VT = -1V; l'inverter INV1 è ideale. Verificare che il circuito si comporta come un multivibratore astabile e determinare la frequenza del segnale di uscita, sapendo che la fase di reset ha una durata pari a T2 = 1.398 ms.

ESERCIZIO 1





$$V_u = R_{15}\, i_{15}$$

$$i_{15} = (h_{fe}+1)\, i_b \, \frac{R_{13}}{R_{13}+R_{14}+R_{15}}$$

$$i_b = (-g_m v_{gs}) \, \frac{(R_4 \| R_{10})}{(R_4 \| R_{10}) + \left\{ R_{11} + h_{ie} + \left[R_{13} \| (R_{14}+R_{15}) \right] (h_{fe}+1) \right\}}$$

$$v_s = (g_m v_{gs}) \left[R_6 + (R_7 \| R_8) \right]$$

$$v_{gs} = v_g - v_s = v_g - g_m v_{gs} \left[R_6 + (R_7 \| R_8) \right] \Rightarrow v_{gs} = \frac{v_g}{1 + g_m \left[R_6 + (R_7 \| R_8) \right]}$$

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

$$\frac{V_u}{V_i} = R_{15} \, \frac{(h_{fe}+1)}{R_{13}+R_{14}+R_{15}} \, \frac{R_{13}}{1} \, (-g_m) \, \frac{R_4 \| R_{10}}{(R_4 \| R_{10}) + R_{11} + h_{ie} + \left[R_{13} \| (R_{14}+R_{15}) \right] (h_{fe}+1)} \, \frac{1}{1 + g_m \left[R_6 + (R_7 \| R_8) \right]}$$

$$\cdot \, \frac{R_2 \| R_3}{R_1 + R_2 \| R_3}$$

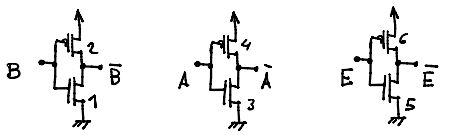
Es "b" Settembre 2020

Monday, September 14, 2020 7:41 PM

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

$N = 2 \times (7 + 3) = 20$

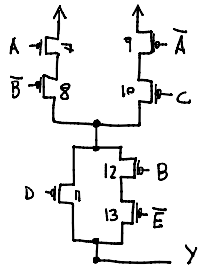
INVERTER:



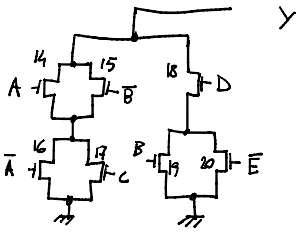
$\left(\frac{W}{L}\right)_{1,3,5} = m = 2$

$\left(\frac{W}{L}\right)_{2,4,6} = p = 5$

PULL-UP N.



PULL-DOWN N.



DIM. PUN

PERCORSI DA 4:

- 7-8-12-13 IMPOSSIBILE (B e $\bar{B}$)
- 9-10-12-13 POSSIBILE

$\left(\frac{W}{L}\right)_{9-10-12-13} = x \rightarrow \frac{1}{x} + \frac{1}{x} + \frac{1}{x} + \frac{1}{x} = \frac{4}{x} = \frac{1}{p}$

$\rightarrow x = 4p = 20$

$\left(\frac{W}{L}\right)_{9,10-12-13} = 4p = 20$

PERCORSI DA 3:

- 7-8-11
- 9-10-11 (CON P-10 GIÀ DIMENSIONATI)

OPZ ① { DIMENSIONO 7-8-11 UGUALI

OPZ. ② { DIMENSIONO '11' USANDO IL PERCORSO P-10-11 E Poi DIMENSIONO '7-8' CON '11' GIÀ DIMENSIONATO

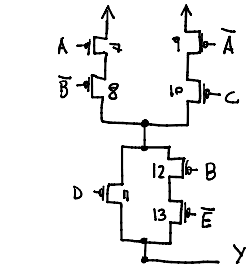
OPZ. 1

$\left(\frac{W}{L}\right)_{7-8-11} = z \rightarrow \frac{1}{z} + \frac{1}{z} + \frac{1}{z} = \frac{3}{z} = \frac{1}{p} \rightarrow z = 3p = 15 \rightarrow \left(\frac{W}{L}\right)_{7,8,11} = 3p = 15$

VERIFICO CHE IL PERCORSO P-10-11 ABBIA $R_{eq} < R_{PMOS-INVERTER}$

$\frac{1}{\underset{(9)}{4p}} + \frac{1}{\underset{(10)}{4p}} + \frac{1}{\underset{(11)}{30}} = \frac{1}{2p} + \frac{1}{3p} = \frac{3+2}{6p} = \frac{5}{6p} < \frac{1}{p}$ OK

PULL-UP N.



OPZ. 2

$\left(\frac{W}{L}\right)_{11} = t \rightarrow \frac{1}{\underset{(1)}{t}} + \frac{1}{\underset{(9)}{4p}} + \frac{1}{\underset{(10)}{4p}} = \frac{1}{t} + \frac{1}{2p} = \frac{1}{p} \rightarrow \frac{1}{t} = \frac{2}{2p} - \frac{1}{2p} = \frac{1}{2p}$

$\rightarrow t = 2p = 10 \rightarrow \left(\frac{W}{L}\right)_{11} = 2p = 10$

$\left(\frac{W}{L}\right)_{7,8} = f$

$\frac{1}{\underset{(7)}{f}} + \frac{1}{\underset{(8)}{f}} + \frac{1}{\underset{(11)}{2p}} = \frac{2}{f} + \frac{1}{2p} = \frac{1}{p} \rightarrow \frac{2}{f} = \frac{1}{2p} \rightarrow f = 4p = 20$

$\left(\frac{W}{L}\right)_{7,8} = 4p = 20$

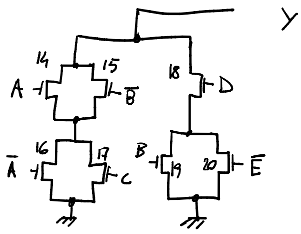
CONFRONTO AREA (USANDO $\frac{W}{L}$, ASSUMENDO $L = L_{min}$)

	Q7	Q8	Q11	SOMMA
OPZ 1	3p	3p	3p	9p
OPZ 2	4p	4p	2p	10p

$A_{OPZ①} < A_{OPZ②}$ SCELGO $\rightarrow \left(\frac{W}{L}\right)_{7,8,11} = 3p = 15$

DIM. PDN

PULL-DOWN N.



• PERCORSI DA 2:

- 14-16 IMPOSSIBILE (A e $\overline{A}$)
- 14-17
- 15-16
- 15-17
- 18-19
- 18-20

} POSSIBILI $\rightarrow \left(\frac{W}{L}\right)_{14,15,16,17,18,19,20} = J$

$$\frac{1}{J} + \frac{1}{J} = \frac{2}{J} = \frac{1}{n} \rightarrow J = 2n = 4$$

$$\left(\frac{W}{L}\right)_{14,15,16,17,18,19,20} = 2n = 4$$

Es "tipo C"

Friday, July 17, 2020 3:27 PM

$V_{CC} = 6V$

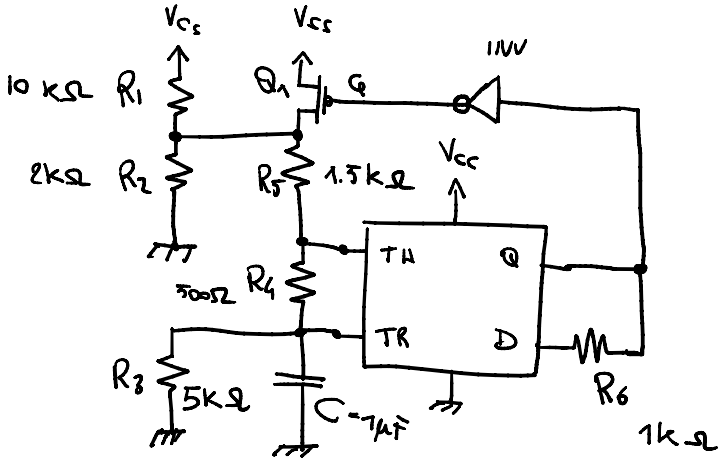
INIZIA IL SET

$V_{TR} = \frac{1}{3} V_{CC}$

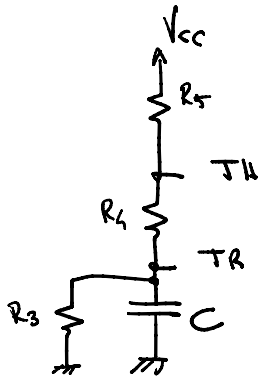
Q = '1' → $V_G = 0V$

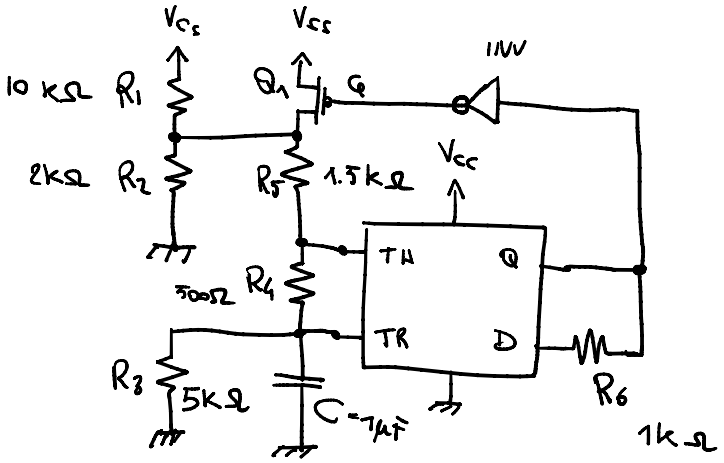
$V_{GS} = -V_{DD} < -|V_{tp}|$

→ Q_1 ON



CIRCUITO EQUIVALENTE:





$$V_{f_1} = V_{CC} \frac{R_3}{R_3 + R_4 + R_5} = V_{CC} \cdot \frac{5}{7} = 4.286\,V$$

$V_{com(1)}$? $V_{TH} = \frac{2}{3} V_{CC} = 4V$ $\quad I_{R_5}^{*} = I_{R_4}^{*} = \frac{V_{CC} - V_{TH}}{R_5}$

$V_{com1} = V_{TR}\,@\,[V_{TH} = \frac{2}{3} V_{CC}] - V_{TH}^{*} - R_4 \cdot I_{R_5}^{*} = 1,3\,mA$

$V_{i1} = \frac{1}{3} V_{CC} = 2V$

$= V_{TH}^{*} - \frac{R_4}{R_5}(V_{CC} - V_{TH}) =$

$= V_{TH}^{*} - \frac{1}{2}(V_{CC} - V_{TH}^{*}) =$

$= \frac{2}{3} V_{CC} - \frac{1}{2} V_{CC} + \frac{1}{2} \cdot \frac{1}{2} V_{CC} =$

$V_{i1} < V_{com12} < V_{f1}$

$2V < 3,\hat{3}V < 4,286V$

$V_{T2} < V_{COM12} < V_{T1}$

$2V < 3,\hat{3}V < 4,296V$

$= V_{TH} - \frac{1}{3}(V_{CC} - V_{TH}) =$

$= \frac{2}{3}V_{CC} - \frac{1}{3}V_{CC} + \frac{1}{3}\cdot\frac{2}{3}V_{CC} =$

$= V_{CC}\frac{6-3+2}{9} = V_{CC}\frac{5}{9} = 3,\hat{3}V$

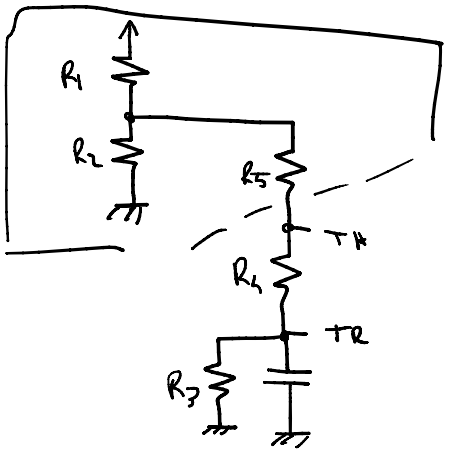
$R_{th} = R_3 \| (R_4 + R_5) = 1,4286\ K\Omega$

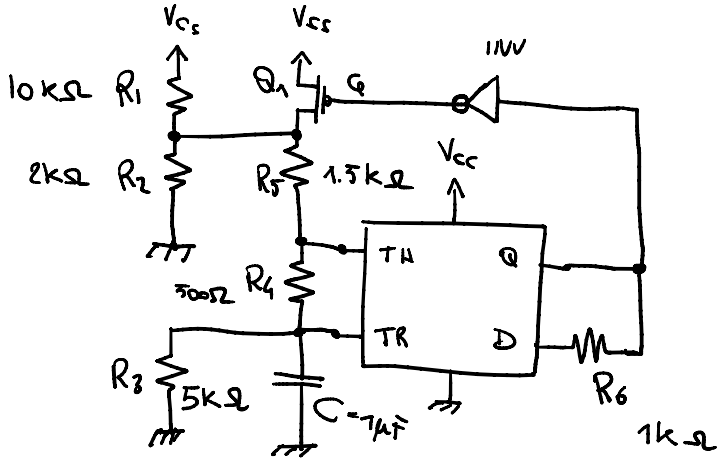
$\tau_1 = R_{th}\cdot C = 1,429\ ms$

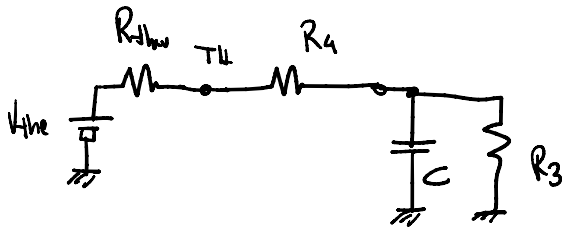
$T_1 = \tau_1 \cdot \ln\left\{\frac{V_{f1} - V_{in}}{V_{f1} - V_{COM12}}\right\} = 1,25\ ms$

RESET :

$Q = '0',\ V_G = V_{CC} \rightarrow V_{GS} = 0V > -|V_{Tp}|$: Q OFF







$V_{ther} = V_{CC}\cdot\frac{R_2}{R_2 + R_1} = \frac{1}{6}V_{CC} = 1V$

$R_{ther} = R_5 + (R_2 \| R_1) = 3,1\hat{6}\ K\Omega$

$V_{i2} = V_{com,2} = 3,\hat{3}\ V$

$V_{f2} = V_{TMax} \dfrac{R_3}{R_3 + R_4 + R_{thLV}} = 577\ mV$

$V_{com21} = \frac{1}{3} V_{cc} = 2V$

$V_{f2} < V_{com21} < V_{i2}$

$0.\overline{577}V < 2V < 3.\hat{3}V$

$R_{V2} = R_3 // (R_4 + R_{thLV}) = 2,115\ K\Omega$

$\tau_2 = R_{V2} \cdot C = 2,115\ ms$

$T_2 = \tau_2 \cdot \ln\left\{\dfrac{V_{f2} - V_{i2}}{V_{f2} - V_{com21}}\right\} = 1,398\ ms$

$T = T_1 + T_2 \simeq 2,649\ ms$

$f = \dfrac{1}{T} = 377,48\ Hz$