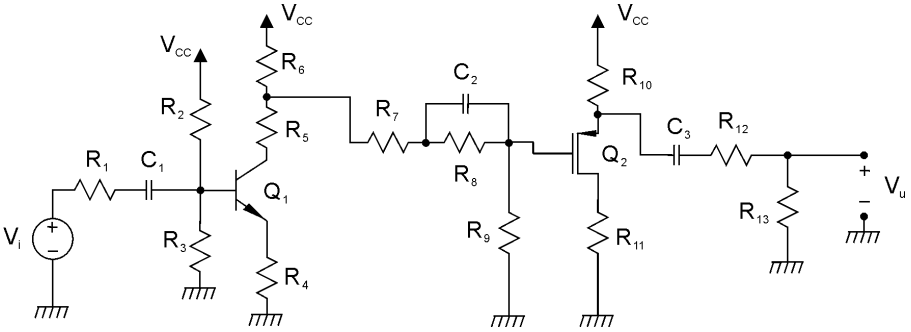
ELETTRONICA DIGITALE

Corso di Laurea in Ingegneria Informatica

Prova scritta del 12 settembre 2017

Esercizio A

R_1 = 50 Ω	R_{10} = 3 kΩ
R_2 = 153 kΩ	R_{11} = 4 kΩ
R_4 = 1 kΩ	R_{12} = 1 kΩ
R_5 = 1.5 kΩ	R_{13} = 20 kΩ
R_6 = 3.2 kΩ	C_1 = 680 nF
R_7 = 200 Ω	C_2 = 47 nF
R_8 = 1.8 kΩ	C_3= 560 pF
R_9 = 18 kΩ	V_{CC} = 18 V



Q_1 è un transistore BJT BC109B resistivo con $h_{re} = h_{oe}= 0$; Q_2 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 = 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 source 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 = 29 kΩ)
2) Determinare l'espressione e il valore di V_U/Vi alle frequenze per le quali C_1, C_2, e C_3 possono essere considerati dei corto circuiti. (R: V_U/Vi=-2.1)
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}=10.34 Hz, f_{Z2}=1881.26 Hz, f_{p2}=2039.5 Hz, f_{Z3}=0 Hz, f_{p3}=13262.9 Hz)

Esercizio B

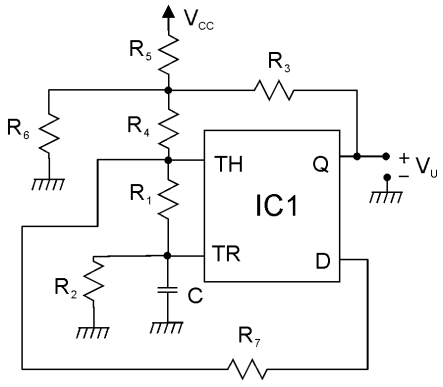
Progettare una porta logica in tecnologia CMOS, utilizzando la tecnica della pull-up network e della pull-down network, che implementi la funzione logica:

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

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 dei transistori. (R: N=20)

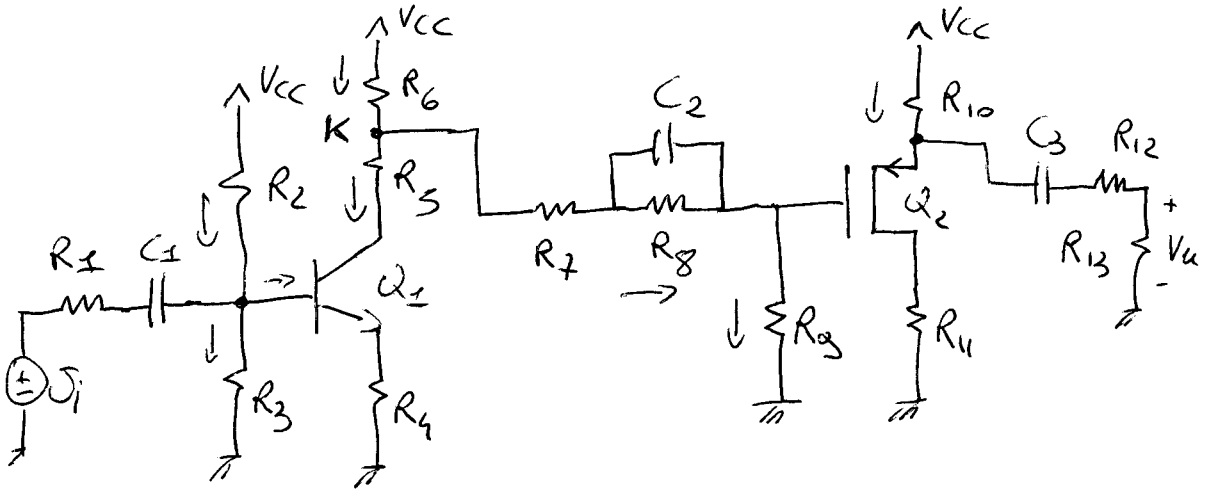
Esercizio C

R_1 =500 Ω	R_6 = 4 kΩ
R_2 = 6.5 kΩ	R_7 = 1 kΩ
R_3 = 2 kΩ	C = 10 nF
R_4 = 200 Ω	V_{CC} = 6 V
R_5 = 2 kΩ	



Il circuito IC_1 è un NE555 alimentato a V_{CC} = 6 V. Determinare la frequenza del segnale di uscita del multivibratore in figura. (R: f= 32261.67 Hz)

ESERCIZIO A



$R_1 = 50\,\Omega$
$R_2 = 153\,k\Omega$
$R_4 = 1\,k\Omega$
$R_5 = 1.5\,k\Omega$
$R_6 = 3.2\,k\Omega$
$R_7 = 200\,\Omega$
$R_8 = 1.8\,k\Omega$
$R_9 = 18\,k\Omega$
$R_{10} = 3\,k\Omega$
$R_{11} = 4\,k\Omega$
$R_{12} = 1\,k\Omega$
$R_{13} = 20\,k\Omega$
$C_1 = 680\,nF$
$C_2 = 47\,nF$
$C_3 = 560\,pF$
$V_{cc} = 18\,V$
$K = 0.5\,mA/V^2$
$V_T = -1\,V$

1) CALCOLARE R_3 per $V_{S2} = 12\,V$

$I_{10} = \frac{V_{cc} - V_{S2}}{R_{10}} = 2\,mA = I_S = I_D$ essendo $I_G = 0$

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

$V_D = R_{11} I_D = 8\,V$

$V_{DS} = V_D - V_S = 8 - 12 = -4\,V < V_{GS} - V_T = -3 + 1 = -2\,V$

$\Rightarrow$ hp SATURAZIONE VERIFICATA

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

$V_G = V_{GS} + V_S = -3 + 12 = +9\,V$

$I_g = \frac{V_G}{R_9} = 0.5\,mA = I_8$

$V_K = V_G + (R_7 + R_8)\,I_8 = 10\,V$

$I_6 = \frac{V_{cc} - V_K}{R_6} = \frac{18 - 10}{3200} = 2.5\,mA$

$I_5 = I_6 - I_8 = 2\,mA = I_C$

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

$V_E = R_4 I_E = 2\,V$

$V_C = V_K - R_5 I_C = 7\,V$

Q_2: $\begin{cases} I_D = 2\,mA \\ V_{DS} = -4\,V \\ V_{GS} = -3\,V \\ g_m = 2 \times 10^{-3}\,\frac{A}{V} \end{cases}$

$= V_C - V_B = 7 - 2 = 5V$

Per $I_C = 2mA$ e $V_{CE} = 5V$ si ha $h_{FE} = 290$, $h_{ie} = 4800\Omega$ e $h_{fe} = 300$

$$I_B = \frac{I_C}{h_{FE}} = 6.8965\,\mu A$$

$$V_B = V_E + V_\gamma = 2 + 0.7 = 2.7V$$

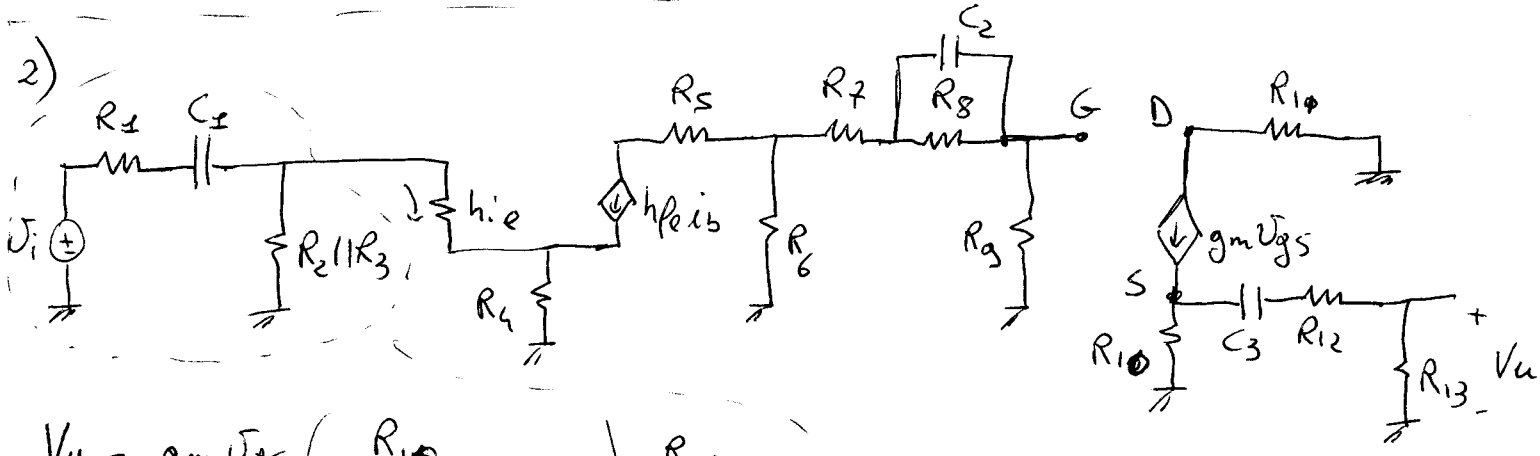
$$I_2 = \frac{V_{CC} - V_B}{R_2} = 0.1\,mA$$

$$I_3 = I_2 - I_B = 9.3103 \times 10^{-5} A$$

$$R_3 = \frac{V_B}{I_3} = 29000\,\Omega$$

Q_1: $I_C = 2mA$, $V_{CE} = 5V$, $h_{FE} = 290$, $h_{ie} = 4800\Omega$, $h_{fe} = 300$

2)

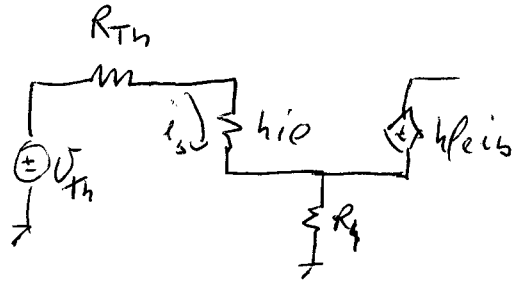


$$V_u = g_m V_{gs} \left(\frac{R_{10}}{R_{10} + R_{12} + R_{13}} \right) \cdot R_{13}$$

$$V_S = (g_m V_{gs}) \left[R_{10} \| (R_{12} + R_{13}) \right]$$

$$V_{gs} = V_g - V_S = \frac{V_g}{1 + g_m \left[R_{10} \| (R_{12} + R_{13}) \right]}$$

$$V_g = (-h_{fe} i_b) \frac{R_6}{R_6 + R_7 + R_9} \cdot R_9$$



$$V_{Th} = V_i \frac{R_2 \| R_3}{R_1 + R_2 \| R_3}$$

$$R_{Th} = R_1 \| R_2 \| R_3$$

$$V_{Th} = (R_{Th} + h_{ie}) i_b + R_4 (h_{fe} + 1) i_b$$

$$i_b = \frac{V_{Th}}{R_{Th} + h_{ie} + R_4 (h_{fe} + 1)} = V_i \frac{\frac{R_2 \| R_3}{R_1 + R_2 \| R_3}}{(R_1 \| R_2 \| R_3) + h_{ie} + R_4 (h_{fe} + 1)}$$

$$\frac{V_o}{V_i} = g_m \frac{R_{10}R_{13}}{R_{10}+R_{12}+R_{13}} \cdot \frac{1}{1+g_m[R_{10}\|(R_{12}+R_{13})]} (-h_{fe}) \frac{R_6 R_9}{R_6+R_7+R_9} \cdot$$

$$\cdot \frac{R_2\|R_3}{R_1+R_2\|R_3} \cdot \frac{1}{(R_1\|R_2\|R_3)+h_{ie}+R_4(h_{fe}+1)} = -2.10776$$

(0.997953; 3.269572×10^{-6})

$$|A_{CB}|_{dB} = 6.476 \text{ dB}$$

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3) POLI E ZERI

C_1: $f_{z1} = 0$ Hz

$$f_{p1} = \frac{1}{2\pi C_1 R_{V1}} = 10.34 \text{ Hz}$$

$$R_{V1} = R_1 + \{R_2\|R_3\|[h_{ie}+R_4(h_{fe}+1)]\} = 22629.06\ \Omega$$

C_2: $$f_{z2} = \frac{1}{2\pi C_2 R_8} = 1881.26 \text{ Hz}$$

$$f_{p2} = \frac{1}{2\pi C_2 R_{V2}} = 2039.50 \text{ Hz}$$

$$R_{V2} = R_8\|(R_7+R_6+R_9) = 1660.34\ \Omega$$

C_3: $f_{z3} = 0$ Hz

$$f_{p3} = \frac{1}{2\pi C_3 R_{V3}} = 13262.91 \text{ Hz}$$

$$R_{V3} = \left(\frac{1}{g_m}\|R_{10}\right) + R_{12} + R_{13} = 21428.57\ \Omega$$

ESERCIZIO B

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

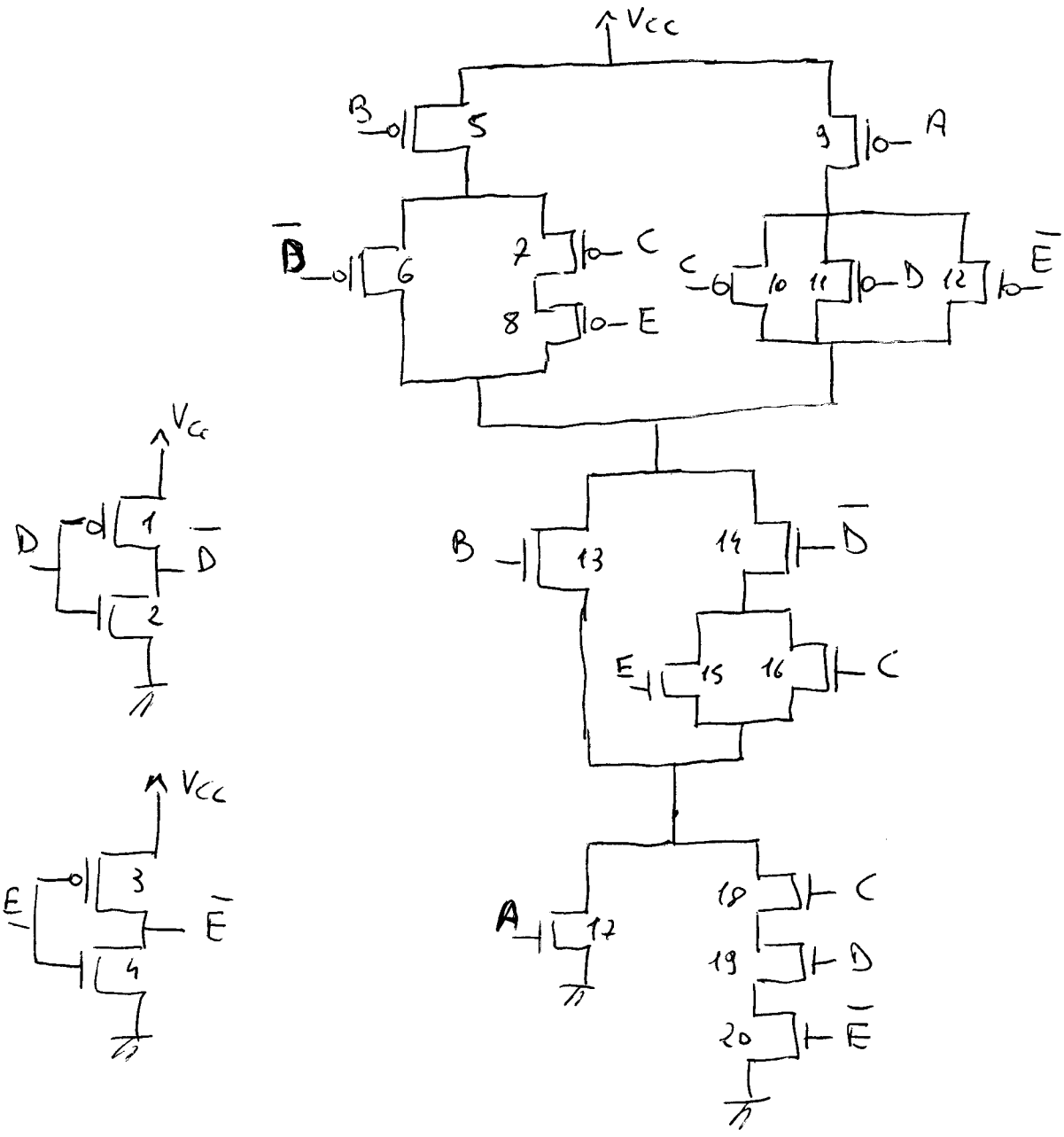
$$= (\bar{B} + \bar{C} + \bar{D})(\bar{A}E + \bar{B}D) + (\bar{C} + \bar{D})(\bar{A}\bar{E}) + \bar{B}\bar{C}\bar{E} + \bar{A}BE =$$

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

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

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

N. MOS = 8 x 2 + 2 x 2 = 20



$\left(\frac{W}{L}\right)_1 = \left(\frac{W}{L}\right)_3 = p = 5$

$\left(\frac{W}{L}\right)_2 = \left(\frac{W}{L}\right)_4 = n = 2$

} INVERTER DI BASE

·) PUN

$Q_5 - Q_7 - Q_8$

$\frac{1}{x} + \frac{1}{x} + \frac{1}{x} = \frac{1}{p} \Rightarrow x = 3p = 15 \Rightarrow \left(\frac{W}{L}\right)_{5,7,8} = 15$

$Q_5 - Q_6$

$\frac{1}{y} + \frac{1}{3p} = \frac{1}{p} \Rightarrow y = \frac{3}{2}p = 7.5 \Rightarrow \left(\frac{W}{L}\right)_6 = 2.5$

$Q_9 - Q_{10}$; $Q_9 - Q_{11}$; $Q_9 - Q_{12}$

$\frac{1}{z} + \frac{1}{z} = \frac{1}{p} \Rightarrow z = 2p = 10 \Rightarrow \left(\frac{W}{L}\right)_{9,10,11,12} = 10$

·) PDN

·) $Q_{14} - Q_{16} - Q_{18} - Q_{19} - Q_{20}$
$Q_{14} - Q_{15} - Q_{18} - Q_{19} - Q_{20}$

} IMPOSSIBILI ($D - \bar{D}$; $E - \bar{E}$)

·) $Q_{13} - Q_{18} - Q_{19} - Q_{20}$

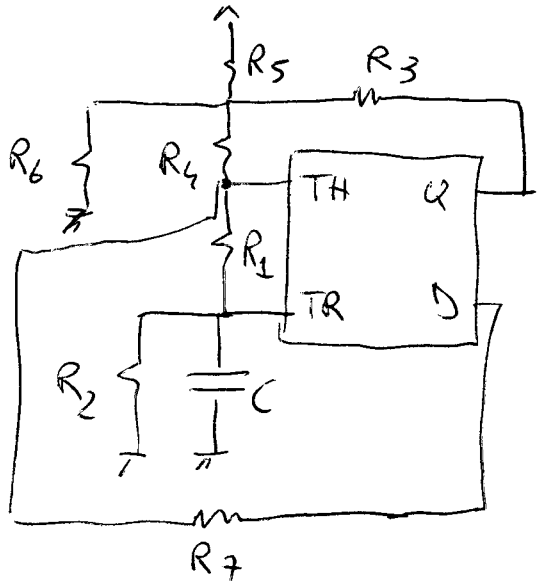
$\frac{1}{x} + \frac{1}{x} + \frac{1}{x} + \frac{1}{x} = \frac{1}{n} \Rightarrow x = 4n = 8 \Rightarrow \left(\frac{W}{L}\right)_{13,18,19,20} = 8$

·) $Q_{14} - Q_{15} - Q_{17}$

$Q_{14} - Q_{16} - Q_7$

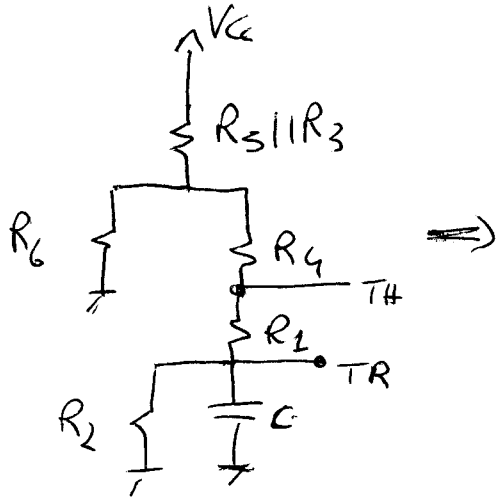
$\frac{1}{y} + \frac{1}{y} + \frac{1}{y} = \frac{1}{n} \Rightarrow y = 3n = 6 \Rightarrow \left(\frac{W}{L}\right)_{14,15,16,17} = 6$

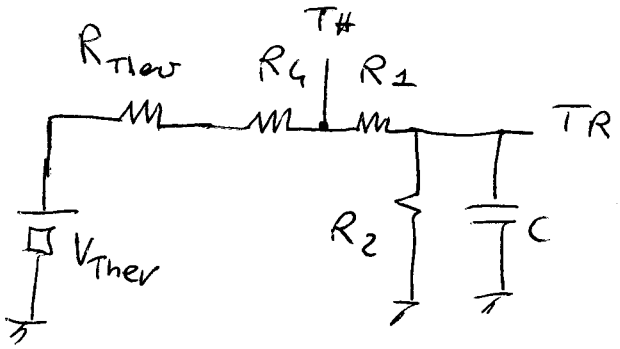
ESERCIZIO C



$R_1 = 500\,\Omega$
$R_2 = 6.5\,k\Omega$
$R_3 = 2\,k\Omega$
$R_4 = 200\,\Omega$
$R_5 = 2\,k\Omega$
$R_6 = 4\,k\Omega$
$R_7 = 1\,k\Omega$
$C = 10\,nF$

1) $Q = 1$
$D = HI$





$$V_{Thev} = V_{cc}\frac{R_6}{R_6 + R_5||R_3} = 4.8\,V$$

$$R_{Thev} = R_3||R_5||R_6 = 800\,\Omega$$

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

$$V_{f1} = V_{Thev}\frac{R_2}{R_{Thev} + R_4 + R_1 + R_2} = 3.9\,V$$

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

$$I_{R1} = \frac{V_{Thev} - V_{TH}}{R_{Thev} + R_4} = 0.8\,mA$$

$$V_{con1} = V_{TH} - R_1 I_{R1} = 3.6\,V$$

$V_{i1} < V_{con1} < V_{f1}$
$2 < 3.6 < 3.9$ OK

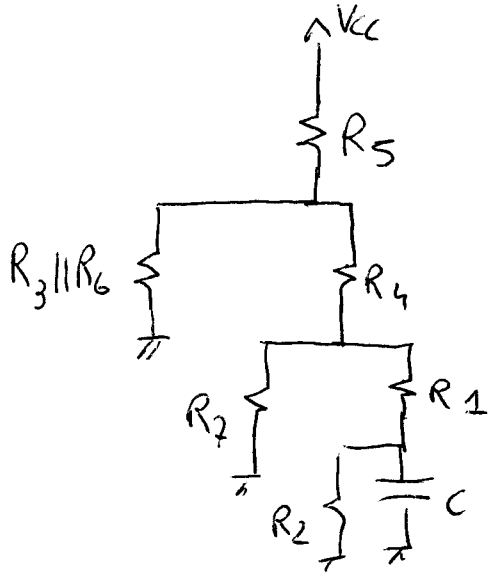
$$R_{U1} = R_2||[R_1 + R_4 + R_{Thev}] = 1218.75\,\Omega$$

$$\tau_1 = C_1 R_{U1} = 12.1875\,\mu s$$

$$T_1 = \tau_1 \ln\left[\frac{V_{i1} - V_{f1}}{V_{con1} - V_{f1}}\right] = 22.496\,\mu s$$

$Q = \phi$

$D = \phi$



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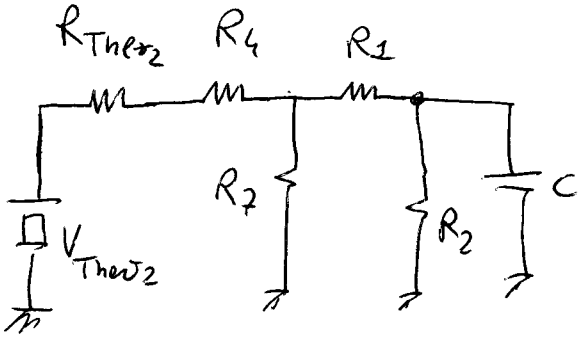

$$V_{Ther2} = V_{cc} \frac{R_6 \| R_3}{(R_6 \| R_3) + R_5} = 2.4V$$

$$R_{Ther2} = R_3 \| R_6 \| R_5 = 800\,\Omega$$

$V_{i2} = V_{con1} = 3.6V$

$V_{con2} = V_{i1} = 2V$

$$V_{f2} = V_{Ther2} \frac{1}{R_{Ther2} + R_4 + R_7 \| (R_1 + R_2)} \cdot \frac{R_7}{R_1 + R_2 + R_7} R_2 = 1.04V$$

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

$3.6 > 2 > 1.04$ ok

$$R_{V2} = R_2 \| \{R_1 + [R_7 \| (R_4 + R_{Ther2})]\} = 866.\bar{6}\,\Omega$$

$\tau_2 = 8.\bar{6}\,\mu s$

$$T_2 = \tau_2 \ln\left(\frac{V_{i2} - V_{f2}}{V_{con2} - V_{f2}}\right) = 8.50\,\mu s$$

$T = T_1 + T_2 = 30.9965\,\mu s$

$$f = \frac{1}{T} = \underline{32261.67}\ Hz$$