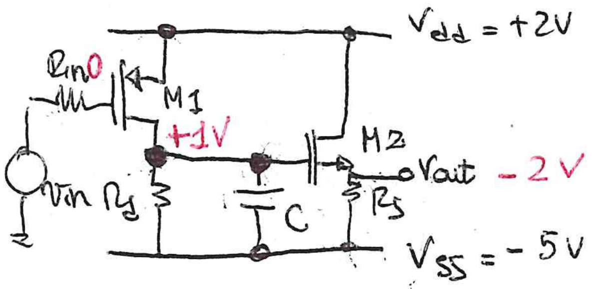
FONDAMENTI DI ELETTRONICA - 4 APRILE 2024 - ESERCITAZIONE ONLINE

ES. 1 - TdE 6/2/2021



$k_n = |k_p| = 0.5 mA/V^2$

$V_{Tn} = |V_{Tp}| = 1V$ $C = 15pF$

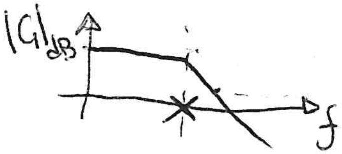
$R_S = 1.5 k\Omega$; $R_d = 12k$; $R_{in} = 100\Omega$

(c) singolarità capacità C

1 polo con $\tau_p = C R_d = 15pF * 12k\Omega = 180 ms \Rightarrow f_p = \frac{1}{2\pi \tau_p} = 880 kHz$

c'è uno zero?

$\exists\ \bar{s}$ t.c. $\forall v_{in}(\bar{s}) \neq 0 \Rightarrow v_{out}(\bar{s}) = 0$ zero solo all'infinito, no zeri al finito



(d) dinamica di uscita

M2) * dinamica negativa: M_2 ~~rischia di spegnersi~~ $\boxed{V_{out_{min}} = V_{SS}} \Rightarrow \Delta V_{out}^{\ominus} = -3V$

* dinamica positiva: M_2 rischia di spegnersi $V_{out_{max}}$ 1 soglia sotto la tensione di gate $V_{GS_2} = V_{Tn}$

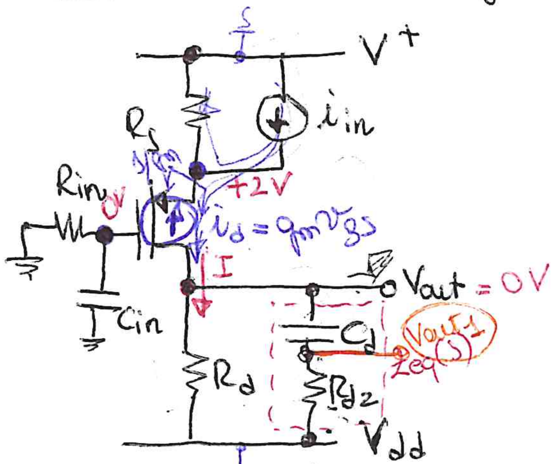
M1) * dinamica positiva $V_{GD} = V_{Tp} \Rightarrow$ non ho margine $\boxed{\Delta V_d^{\oplus} = 0}$

* dinamica negativa V_{D_1} potrebbe scendere fino alla alimentazione V_{SS}

↳ limite della dinamica negativa è dato da M2, limite della dinamica positiva è dato da M_1

$$\boxed{-3 \leq \Delta V_{out} \leq 0}$$

ES.1 3° appello - 17 gennaio 2023



$V_{dd} = -6V$; $V^+ = +4V$

$C_d = 220mF$; $C_{in} = 10\mu F$

$R_d = 6k$; $R_{d_2} = 12k$

$R_{in} = 100k\Omega$; $V_{Tp} = -1V$

$\mu_n = 1200 \, cm^2/Vs$; $\mu_p = 450 \, cm^2/Vs$

$|k_p| = \frac{1}{2}\mu_p C_{ox}\left(\frac{W}{L}\right)_p = 1mA/V^2$

ⓐ Polarizzazione del circuito con R_S t.c. $V_{out} = 0$

- ★ i_{in} spento
- ★ Capacità circ. aperti
- ★ pMOS saturo (Hp)

$I = -I_d$

$I = \frac{V_{out} - V_{dd}}{R_d} = \frac{0 - (-6V)}{6k} = 1mA$

$I = |k_p| (V_{GSp} - V_{Tp})^2$ $\quad V_{GSp} = V_{Tp} \pm \sqrt{\frac{I}{|k_p|}} = -1V \pm \sqrt{\frac{1mA}{1mA/V^2}} = (-1 \pm 1)V =$

$= \begin{cases} 0V & \text{non accettabile poiché} > V_{Tp} \text{ pMOS spento} \\ -2V < V_{Tp} & \text{OK} \end{cases}$

$V_G = 0V \Rightarrow V_S = +2V$

$I R_S = V^+ - V_S \Rightarrow R_S = \frac{V^+ - V_S}{I} = \frac{+4V - 2V}{1mA} = 2k\Omega$

$V_{GD} = 0V - 0V = 0V > V_{Tp}$ OK pMOS saturo

$g_m = 2k_p(V_{GS} - V_{Tp}) = 2(-1mA/V^2)(-2V+1V)$
$= 2mS \Rightarrow 1/g_m = 500\Omega$

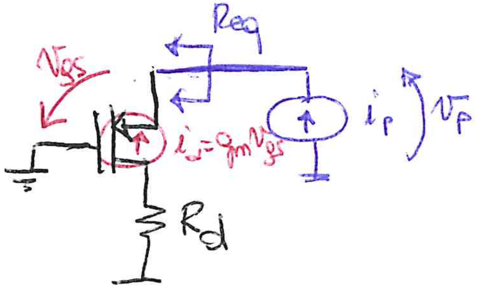
ⓑ "guadagno" di piccolo segnale a bassa frequenza con $r_0 = \infty$

- partitore di corrente al modo di source $\quad -i_d = i_{in} \frac{R_S}{1/g_m + R_S}$

$v_{out}\Big|_{LF} = -i_d R_d = i_{in} \frac{R_S}{1/g_m + R_S} R_d$

⇓

$|T|\Big|_{LF} \triangleq \frac{v_{out}}{i_{in}}\Big|_{LF} = + \frac{R_S}{1/g_m + R_S} R_d = + \frac{2k}{2.5k} * 6k = +4.8k\Omega$



$R_{eq} \triangleq \frac{v_p}{i_p} = \frac{v_p}{g_m v_p} = \frac{1}{g_m}$

$i_p = -i_d =$; $v_p = -v_{gs}$
$= -g_m(-v_p)$

(c) singolarità introdotte nel trasferimento v_{out}/i_{in}

2 capacità

C_{in} non vede variare la tensione ai suoi capi ⇒ non introduce singolarità!

C_d: 1 polo $\tau_p = C_d (R_d + R_{d_2}) = 220nF(6k+12k) = 3960\mu s = 3.96 ms$

$\hookrightarrow f_p = \frac{1}{2\pi \tau_p} = 40 Hz$

zero: $Z_{eq}(s) = \frac{1}{sC_d} + R_{d2} = 0 \Rightarrow$ zero $\exists \bar{s}$ t.c. $\forall i_{in}(\bar{s}) \neq 0$ $v_{out}(\bar{s}) = 0$

$\frac{1 + sC_d R_{d2}}{sC_d} = 0$ $1 + sC_d R_{d_2} = 0 \Rightarrow s_z = -\frac{1}{\tau_z} = -\frac{1}{C_d R_{d2}}$

$\hookrightarrow \tau_z = C_d R_{d_2} = 220nF * 12k\Omega = 2640\mu s = 2.64 ms$

$\hookrightarrow f_z = \frac{1}{2\pi \tau_z} = 60 Hz$

per V_{out_1} il polo sarebbe lo stesso; lo zero sarebbe nell'origine

(d) n° quadri

B $D = 10^{13} cm^{-2}$ drogante di tipo p

↳ dose

resistenza per quadro $R_\square = \frac{1}{q\mu_p D} = \frac{1}{1.6 \cdot 10^{-19} C * 450 cm^2/V s * 10^{13} cm^{-2}} = 1.38 k\Omega/\square$

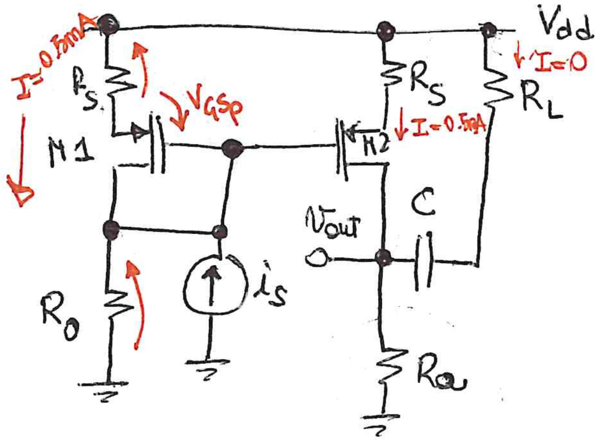
$R_d = 6k$ $R_d = n°_{quadri} * R_\square$ $n°_{quadri} = \frac{R_d}{R_\square} = \frac{6k\Omega}{1.38 k\Omega/\square} = 4.35 \square$

$4\square \Rightarrow R_{reale} = 5.52k$

$\Delta R = 8\%$

$\Delta R = \frac{6k - 5.52k}{6k} = \frac{0.48k}{6k}$

ES. 3   1° appello   14 luglio 2015



$R_S = 2k\Omega$ $C = 47nF$

$R_a = R_L = 3k\Omega$ $V_{dd} = +5V$

$|k_p| = \frac{1}{2}\mu_p C_{ox}\frac{W}{L} = 0.5mA/V^2$

$|V_{Tp}| = 0.5V$

ⓐ Det. R_0 t.c. $I = 0.5mA$ in ogni MOS

- ★ spegnere i gen. di segnale
- ★ Capacità circuiti aperti
- ★ Hp pMOS saturi

M_1 Transdiodo ⇒ saturo $(V_{GD_1} = 0)$

$$V_{dd} - 0V = IR_S - V_{GSp} + IR_0$$

$$0.5mA = I = |k_p|(V_{GSp} - V_{Tp})^2 \Rightarrow V_{GSp} = \pm\sqrt{\frac{0.5mA}{|k_p|}} + V_{Tp} = \pm 1 - 0.5V = \begin{cases} +0.5V > V_{Tp} \text{ NO} \\ -1.5V < V_{Tp} \text{ OK} \end{cases}$$

$$V_{dd} = I(R_S + R_0) - V_{GSp}$$

$$V_{G_1} = V_{dd} - IR_S + V_{GSp} = 5V - 1V - 1.5V = 2.5V$$

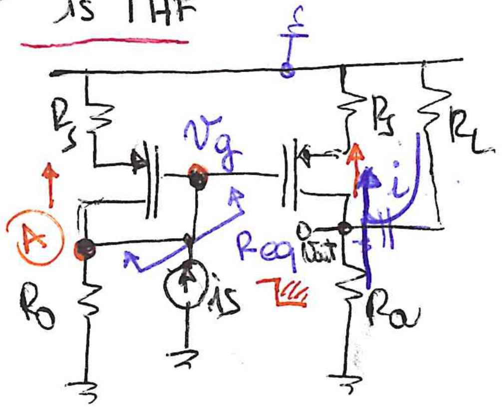
$$5V = 0.5mA * 2k + 0.5mA\, R_0 + 1.5V \Rightarrow R_0 = 5k\Omega$$

$$V_{out} = I * R_a = 0.5mA * 3k\Omega = +1.5V$$

$$V_{GD} = 2.5V - 1.5V = +1V > V_{Tp} \text{ OK pMOS saturo}$$

$$g_m = 2k_p(V_{GSp} - V_{Tp}) = 1mS \Rightarrow 1/g_m = 1k$$

ⓑ $\left.\frac{v_{out}}{i_s}\right|_{HF}$



$$R_{eq} = R_0 // (1/g_m + R_S)$$

$$v_g = i_s R_{eq}$$

$$i = \frac{v_g}{1/g_m + R_S}$$

$$v_{out} = -i(R_a//R_L) = -\frac{v_g}{1/g_m + R_S}(R_a//R_L) = -\frac{i_s R_{eq}}{1/g_m + R_S}(R_a//R_L)$$

$$\Downarrow\; T = \left.\left(\frac{v_{out}}{i_s}\right)\right|_{HF} = \frac{-R_0//(1/g_m + R_S)}{1/g_m + R_S} R_a//R_L = -\frac{R_0\,\cancel{(1/g_m + R_S)}}{R_0 + 1/g_m + R_S}\cdot\frac{R_a//R_L}{\cancel{1/g_m + R_S}} =$$

$$= -\frac{R_0}{R_0 + 1/g_m + R_S} * 1 * (R_a//R_L) = 0.94k\Omega$$

- 1 : fattore di specchiamento
- $\frac{R_0}{R_0 + 1/g_m + R_S}$: partitore di corrente al nodo Ⓐ
- $(R_a//R_L)$: carico sul drain di M_2

(c) max valore di R_a

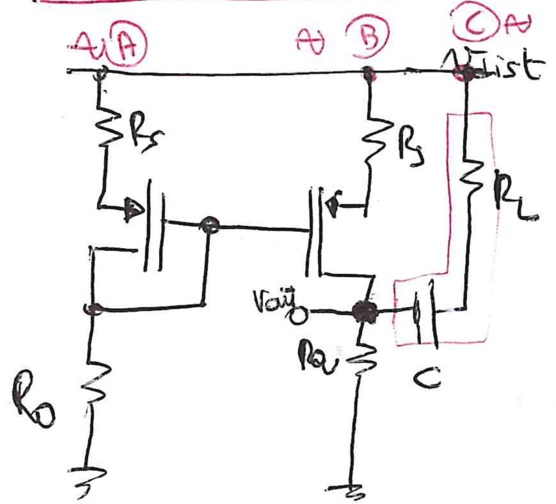
M_2 saturo $\quad V_{GD_2} > V_{Tp}$

$$V_{G_2} - V_{D_2} > V_{Tp} \Rightarrow V_{D_2} < V_{G_2} - V_{Tp} = 2.5V - (-0.5V) = 3V$$

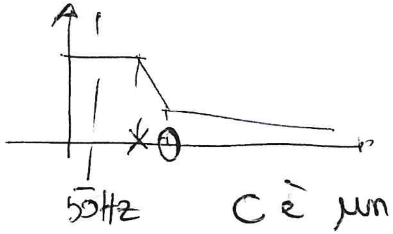
$$V_{D_2}\big|_{max} = +3V$$

$$V_{D_2} = I * R_a \Rightarrow R_{a\,max} = \frac{V_{D_2\,max}}{I} = \frac{3V}{0.5mA} = 6k\Omega$$

(d) effetto su Vout di un disturbo su V_{dd} con Ampiezza $A = 10mV$ e frequenza $f = 50Hz$



* per (A) e (B)



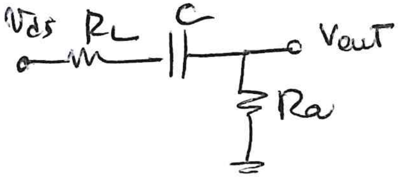
C introduce
- un polo con $\tau_p = C(R_a + R_L) \Rightarrow f_p = 564Hz$
- uno zero con $\tau_z = CR_L \Rightarrow f_z = \frac{1}{2\pi\tau_z} = 1kHz$

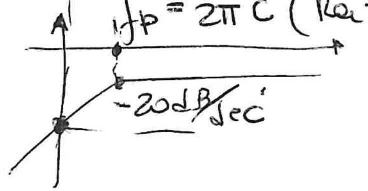
$R_L + 1/sC = 0$

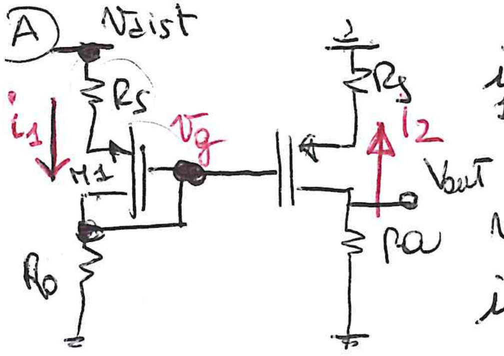
C è un aperto

$$f_p = \frac{1}{2\pi C(R_a + R_L)} = 564Hz$$

* ingresso su (C)





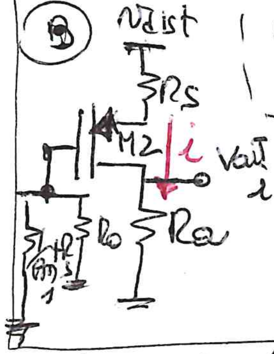


$$i_1 = \frac{v_{dist}}{R_s + 1/g_{m_1} + R_o}$$

$$v_g = i R_o$$

$$i_2 = \frac{v_g}{1/g_{m_2} + R_s}$$

$$v_{out} = -i_2 R_a = -\frac{R_a}{\dots} R_o \frac{v_{dist}}{\dots} = -10mV \frac{3k}{\dots} \cdot \frac{5k}{2k + 1k + 5k} = -10mV\frac{5}{8}$$



$$v_{out}\Big|_{HF} = \frac{R_a}{R_a + R_L} v_{dist} = \frac{v_{dist}}{2}$$

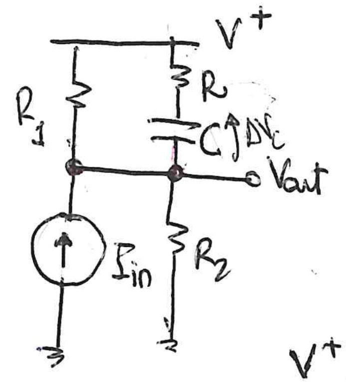
@ 50Hz $\Rightarrow v_{out}\Big|_{(C)\,v_{dist}} \simeq \frac{v_{dist}}{20} = \frac{10mV}{20} = 0.5mV$

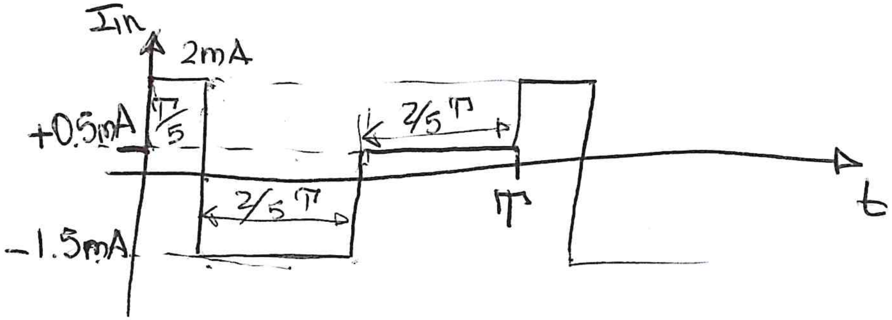
$$i = \frac{v_{dist}}{R_s + 1/g_{m_2}}$$

$$v_{out\,(B)} = i R_a = \frac{10mV}{2k + 1k} 3k = 10mV$$

$$v_{out}\Big|_{v_{dist}} = v_{out(A)} + v_{out(B)} + v_{out(C)} = -10mV\frac{5}{8} + 10mV = 10mV\frac{3}{8} + \dots$$

ESERCIZIO





ES Ø: τ, $\langle V_{out} \rangle$ con $T = 20\,ms$

ES. 1 a) $V_{out}(t)$ con $T = 20\,ms$

b) ~~...~~ con $T = 320\,\mu s$ ... condensatore

$V^+ = 2V \quad R_1 = R_2 = 10\,k\Omega \quad R = 3\,k\Omega \quad C = 2\,nF$

ES Ø

$$\tau = C\left(R_1 /\!/ R_2 + R\right) = 16\,\mu s$$

$$\frac{T}{5} = \frac{20\,ms}{5} = 4\,ms \qquad \tau \ll \frac{T}{5}$$

circuito va a regime in ogni frat. del periodo

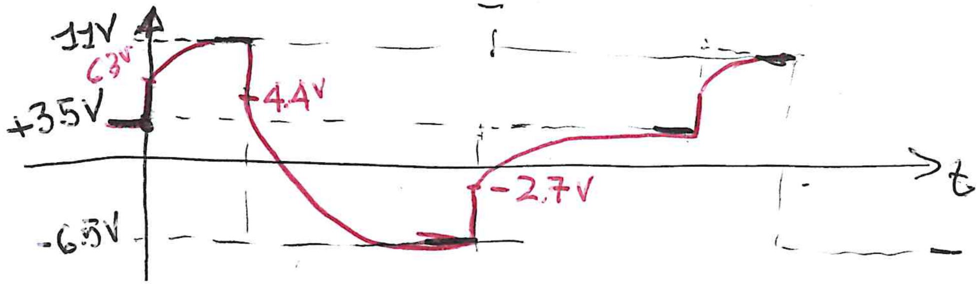
$$\langle V_{out} \rangle = V^+ \frac{R_2}{R_1 + R_2} + \langle I_{in} \rangle \left(R_1 /\!/ R_2\right) = \frac{2V}{2} + \langle I_{in} \rangle\, 5k = +1V$$

$$\langle I_{in} \rangle = \frac{1}{T}\left[2mA \cdot \frac{1T}{5} - 1.5mA\,\frac{2T}{5} + 0{,}5\,mA\,\frac{2T}{5}\right] = \frac{2}{5}\,mA - \frac{3}{5}\,mA + \frac{1}{5}\,mA = 0\,mA$$

ES. 1

$$V_{out}\Big|_{regime} = I_{in}\Big|_{regime} \cdot \left(R_1 /\!/ R_2\right) + \underbrace{V^+ \frac{R_2}{R_1 + R_2}}_{+1V} =$$

- $-1.5mA$: $= -1.5mA\ 5k + 1V = -6.5V$
- $0.5mA$: $= 0.5mA \cdot 5k + 1V = 3.5V$
- $2mA$: $= 2mA \cdot 5k + 1V = 11V$



Sul fronte

$$\Delta V_{out} = \Delta I_{in}\Big|_{fronte} \left(R_1 /\!/ R_2 /\!/ R\right) =$$

$\frac{15k^2}{8k} = 1.9k$

- $+1.5mA$: $2.8V$
- $-3.5mA$: $-6.65V$
- $+3.8V$

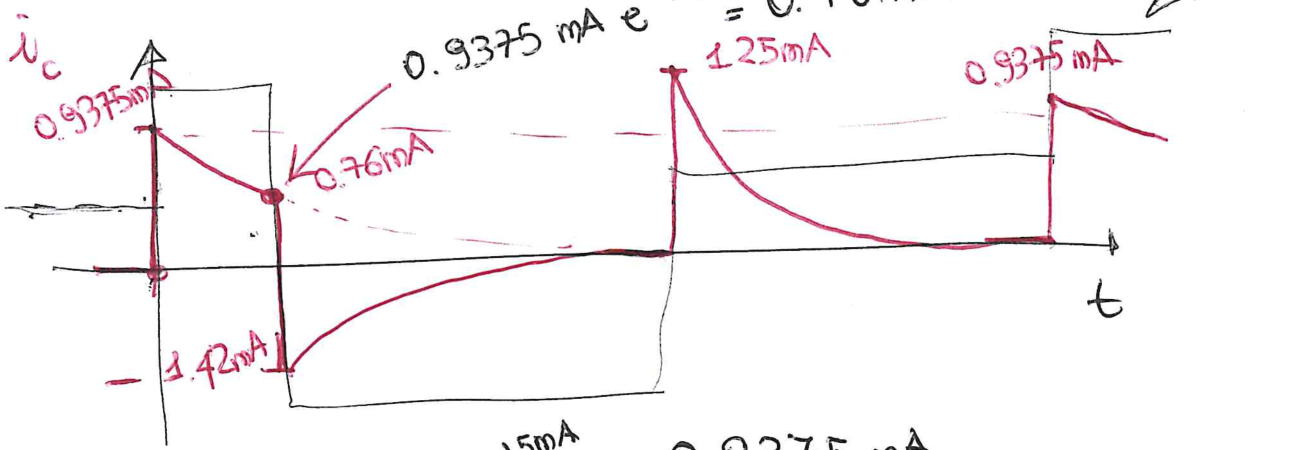
$$\Delta I_{in}\Big|_{fronte} =$$

- $+1.5mA$ (da 0,5mA a 2mA)
- $-3.5mA$ (da 2mA a $-1.5mA$)
- $+2mA$ (da $-1.5mA$ a 0.5mA)

(b) $\frac{T}{5} = 64\mu s < 5\tau$ non va a regime

$\frac{2}{5}T = 128\mu s = 6\tau > 5\tau$ va a regime

$0.9375\,mA\, e^{-t/\tau} = 0.76\,mA$ (t = T/5)



$\Delta I_c = \Delta I_{fronte} \frac{R_1 \| R_2}{R_1 \| R_2 + R}$

ΔI_{fronte}	ΔI_c
$\Delta I_{fronte} = 1.5mA$	0.9375 mA
- 3.5mA	2.1875 mA
2mA	1.25mA