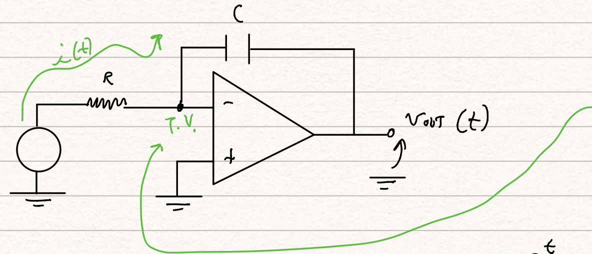
INTEGRATORE DI MILLER



IN CONTINUA IL CIRCUITO NON È RETROAZIONATO E QUINDI NON HO UNA TERRA VIRTUALE

$$i(t) = \frac{v_{IN}(t)}{R} \qquad Q(t) = \int_0^t i(\tau)\,d\tau$$

carica depositata sulle armature di C

$$v_C(t) = V_C + \frac{Q(t)}{C} = V_C + \frac{\int_0^t i(\tau)\,d\tau}{C} = V_C + \frac{1}{RC}\int_0^t v_{IN}(\tau)\,d\tau$$

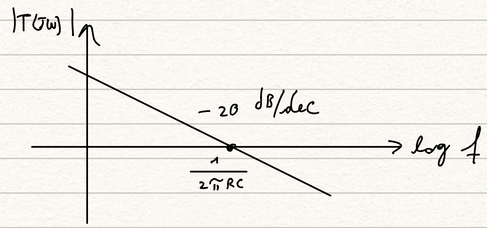
$$V_{OUT}(t) = -V_C(t) = -V_C + \frac{1}{RC}\int_0^t v_{IN}(\tau)\,d\tau$$

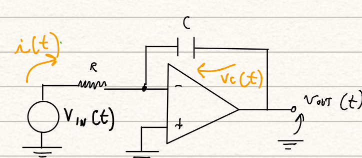
$RC \rightarrow$ costante di tempo di integrazione

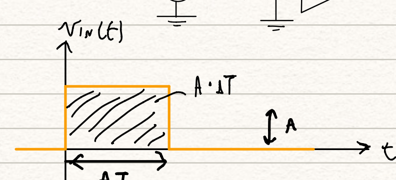
$$Z_1(s) = R \qquad Z_2(s) = \frac{1}{sC}$$

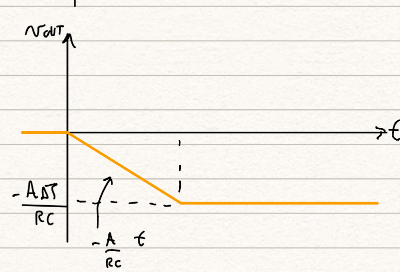
$$T(s) \triangleq \frac{V_{OUT}(s)}{V_{IN}(s)} = \frac{-Z_2(s)}{Z_1(s)} = -\frac{1}{sRC}$$

$$|T(j\omega)| = \frac{1}{\omega RC}$$

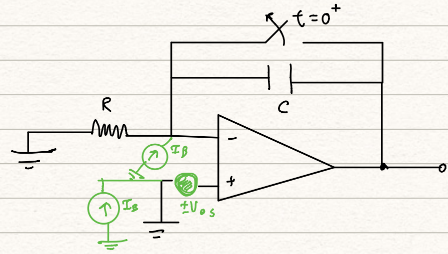








EFFETTO DELLE NON LINEARITÀ DELL' OP. AMP SULL'INTEGRATORE DI MILLER



$t \le 0^-$ $\quad V_{out}(t) = \pm V_{os}$

$t = 0^+$ $\quad$ l'interruttore si apre

applichiamo il fattore di sovrapposizione degli effetti

$\boxed{V_{os}}$ $\quad V_{OUT}\Big|_{V_{oS}} = \pm V_{os} + \dfrac{\int_0^t \pm \frac{V_{oS}}{R}\, d\tau}{C} = \pm V_{os} \pm \dfrac{V_{oS}}{RC}\, t$ $\quad \leftarrow i(\tau)$

$\boxed{I_B}$ $\quad I_B$ al $\oplus$ non da contributo

I_B al $\ominus$; $v^+ = 0 \longrightarrow v^- = 0$ (terra virtuale) in R

$$V_{out}(t)\Big|_{I_B} = -\frac{Q(t)}{C} = -\frac{\int_0^t I_B\, d\tau}{C} = -\frac{I_B}{C}\, t$$

$$V_{out}(t) = \pm V_{os} \pm \frac{V_{os}}{RC}\, t - \frac{I_B}{C}\, t$$

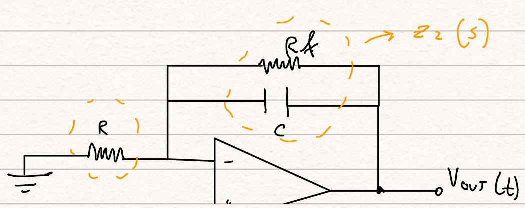
dopo quanto tempo l'uscita satura?

$|V_{OUT}|_{SAT}| = 10V$

$R = 10\ k\Omega$
$C = 100pF$
$V_{oS} = \pm 1,5\ mV$
$I_B = 100\ nA$

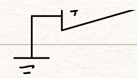
$$\Delta t = \frac{V_{OUT}|_{SAT} \mp V_{os}}{\pm \frac{V_{oS}}{RC} - \frac{I_B}{C}} \simeq \frac{-10V}{-\frac{1.5mV}{10k \cdot 100p} - \frac{100\,nA}{100\,p}} = \frac{10}{1,5 \cdot 10^3 + 10^3} = \frac{10}{2,5 \cdot 10^3} \simeq 4ms$$

INTEGRATORE APPROSSIMATO:

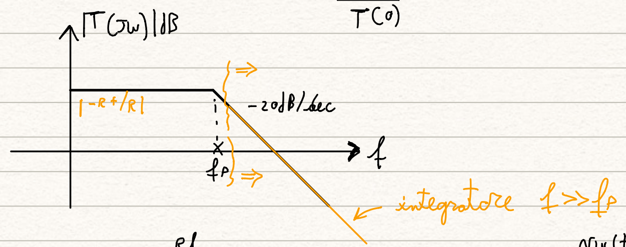


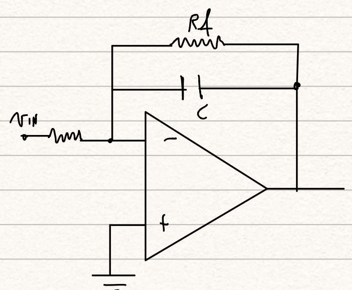
$Z_2 = \dfrac{Rf}{1+sCRf}$

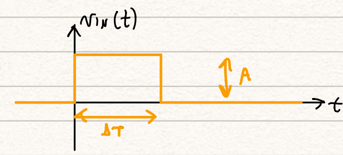
$Z_1 = R$

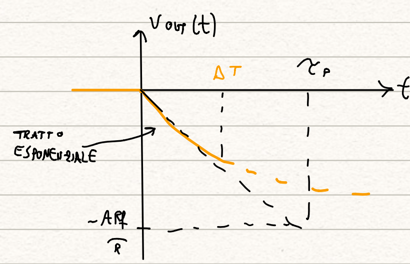


$$T(s) \triangleq \frac{V_{out}(s)}{V_{in}(s)} = -\frac{Z_2(s)}{Z_1(s)} \simeq \underbrace{-\frac{R_f}{R}}_{T(0)} \cdot \frac{1}{1+sCR_f} \qquad f_p = \frac{1}{2\pi \tau_p} \qquad \tau_p = CR_f$$



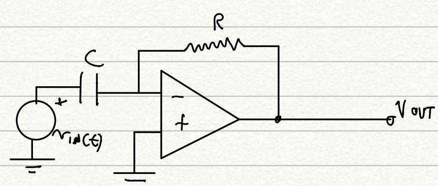






$$-A\frac{R_f}{R} \cdot \frac{1}{\tau} t = -A\frac{R_f}{R} \cdot \frac{1}{CR_f} t \Big|_{t=\Delta T} = -\frac{A}{RC} \Delta T$$

CIRCUITO DERIVATORE



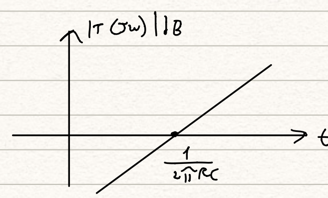
ANALISI NEL DOMINIO DEL TEMPO

$$i(t) = C\frac{dv_C}{dt} = C \cdot \frac{dv_{in}(t)}{dt}$$

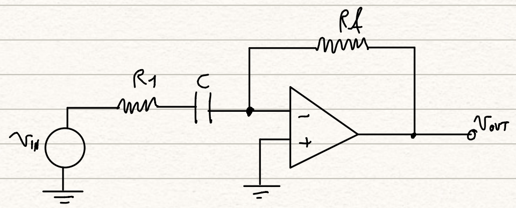
COSTANTE DI TEMPO DI DERIVAZIONE

$$v_{out}(t) = -i(t)R = -RC\frac{dv_{in}}{dt}(t)$$

$$T(s) = -\frac{R}{1/sC} = -RSC$$



DERIVATORE APPROSSIMATO



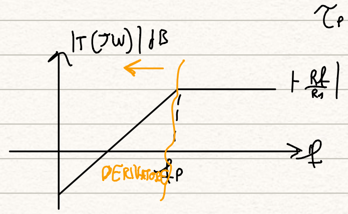
$$Z_2(s) = R_f$$

$$Z_1(s) = R_1 + \frac{1}{sC} = \frac{R_1 sC + 1}{sC}$$

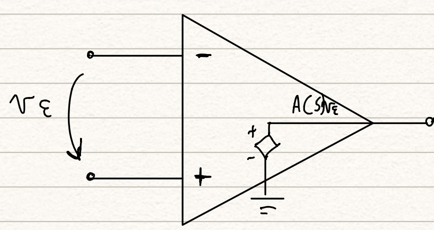
$$T(s) = -\frac{Z_2(s)}{Z_1(s)} = -\frac{R_f sC}{1 + \underbrace{sCR_1}}$$

$$\tau_p = CR_1$$

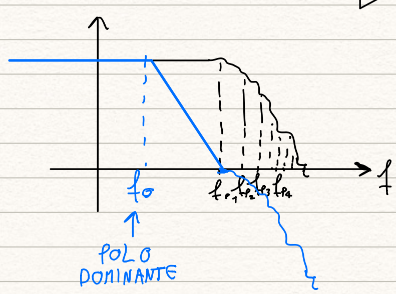
$$\frac{-sCR_f}{sC\,R_1} = \frac{-R_f}{R_1}$$



RISPOSTA IN FREQUENZA E LARGHEZZA DI BANDA DELL' AMPLIFICATORE OPERAZIONALE



$$V_{OUT} = A(s)\,v_\varepsilon$$



guadagno ad anello aperto in continua dell' opamp.

$$A(s) = \frac{A_0}{1 + s\tau_0}$$

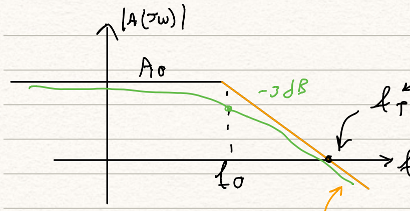
COSTANTE DI TEMPO AD ANELLO APERTO DELL' OPAMP

$$A(j\omega) = \frac{A_0}{1 + j\omega\tau_0} = \frac{A_0}{1 + j\frac{\omega}{\omega_0}}$$

guadagno in continua ad anello aperto

$$|A(j\omega)| = \frac{A_0}{\sqrt{1 + \frac{\omega^2}{\omega_0^2}}} \qquad \omega_0 = \frac{1}{\tau_0}$$

pulsazione a -3dB (ad anello aperto)

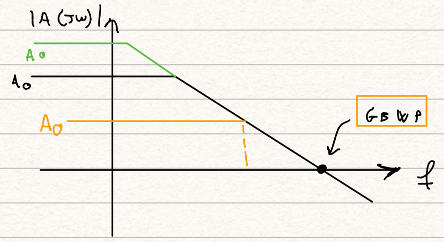


f_T ← frequenza di taglio

$$f_0 = \frac{1}{2\pi \tau_0}$$

$$|A(j\omega)| \simeq \frac{A_0}{\sqrt{\frac{\omega^2}{\omega_0^2}}} = \frac{A_0 \omega_0}{\omega}$$

@ $\omega_T = 2\pi f_T$



GBWP
Gain BandWidth Product

A_0 $10^5 \div 10^9$ typ

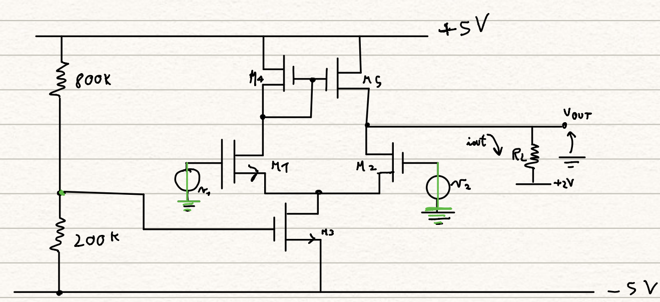
f_0 10 – 100 Hz

$A_0 f_0 = 10^6 \div 10^9$ GBWP = 1 MHz ÷ 1 GHz GBWP ≃ 10 GHz

---

ESERCITAZIONE SU STADI DIFFERENZIALI CON CARICO A SPECCHIO:

esercizio: stadio differenziale con carico a specchio:



DATI:
$|V_{Tp}| = V_{Tn} = 1V$
$|K| = 125 \mu A/V^2$ → M1, M2, M4, M5
$M_3 : K_3 = 375 \mu A/V^2$
$r_{o3} = 50 k\Omega$

a) polarizzazione
b) i_{out}/v_d?
c) i_{out}/v_{cm}?

a) POLARIZZAZIONE:

HP: mos saturi

$$V_{G3} = -5V + \frac{200k}{(200+800)k}\left[5V - (-5V)\right] = -3V$$

TRASCURO r_{o3} (salvo verificare che $I_{ro3} \ll I_{n3}$)

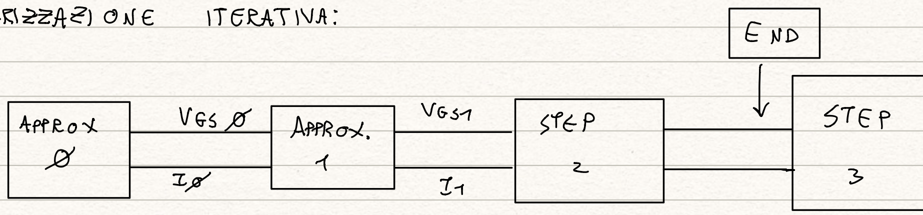
$$I_3 = K_3 (V_{GS_3} - V_{Tn})^2 = 375\,\mu A$$

$$I_1 = I_2 = \frac{I_3}{2} = 187{,}5\,\mu A \qquad I_1 = I_2 = K(V_{GS} - V_{Tn})^2$$

$$\hookrightarrow V_{GS1} = V_{GS2} = V_{GS} = V_{Tn} \pm \sqrt{\frac{I_1}{K}} = V_{Tn} + \sqrt{\frac{187{,}5\,\mu A}{125\,\mu A}} = 2{,}2V$$

$$I_{ro_3} = \frac{-2{,}2V - (-5V)}{r_{o3}} = 56\,\mu A \,!!!$$

POLARIZZAZIONE ITERATIVA:



$$I_1\Big|_1 = I_2\Big|_1 = \frac{I_3}{2} + \frac{I_{ro3}}{2} = \frac{375\,\mu A + 56\,\mu A}{2} = 215{,}5\,\mu A$$

$$V_{GS}\Big|_1 = V_{Tn} + \sqrt{\frac{215{,}5\,\mu A}{125\,\mu A/V^2}} = 2{,}31V$$

$$V_{DS_3} = -2{,}31V - (-5V) = 2{,}7V$$

$$I_{ro_3} = \frac{V_{DS3}}{r_{o3}} = 54\,\mu A \qquad (56\,\mu A)$$

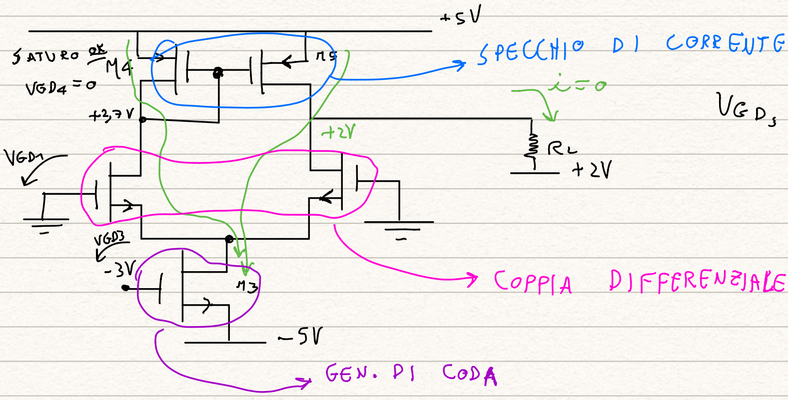
3,6%

$\Downarrow$ ok

$$I_{n_{3TOT}} = 375\,\mu A + 54\,\mu A$$

$$I_1 = I_2 = \frac{I_{3TOT}}{2}$$

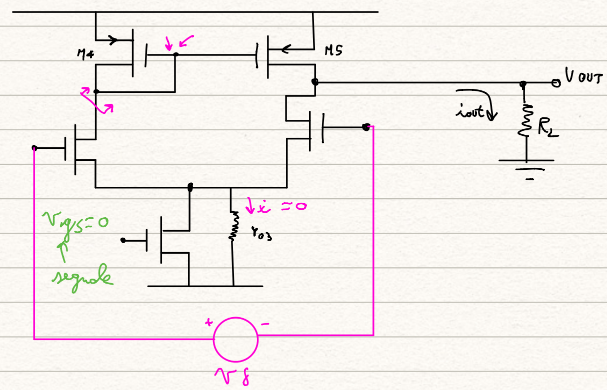
$$g_{m1} = g_{m2} = 328\,\mu A/V \qquad g_m = 2K(V_{GS} - V_{Tn})$$

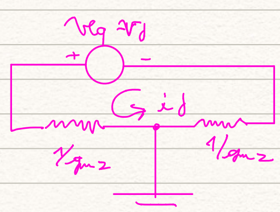


$V_{GD_5} = -3V + 2,3V < 0$ OK

$V_{GP_1} = -3,7V < 0 < V_{Tn}$ OK M

b) COMPORTAMENTO SU SEGNALE DIFFERENZIALE



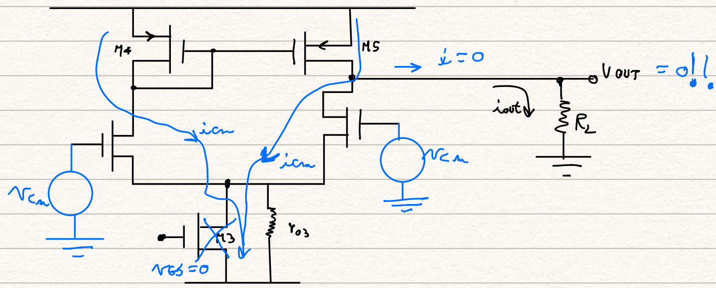


$$i_d = \frac{v_d}{1/g_{m1} + 1/g_{m2}}$$

$$i_{out} = 2 i_d \longrightarrow v_{out} = 2 i_d R_L = 2 \frac{v_d}{2/g_m} R_L$$

$$G_{diff} = \frac{v_{out}}{v_d} = g_m R_L = 328\ \mu A/V \cdot 10\,k\Omega = +3,28$$

c) Analisi su segnale di modo comune



$G_{cm}=0!!$

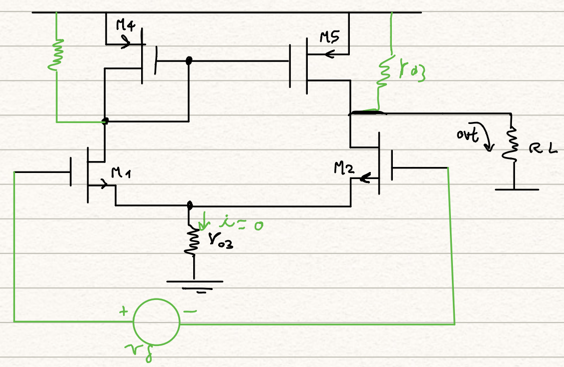
$i\,r_{o3} = i_{cm}+i_{cm} = 2\,i_{cm}$

grazie allo specchio

d) M4 e M5 con ro $|V_A| = 25V$

$$r_{o4} = r_{o5} = \frac{|V_A|}{I_4} = \frac{25V}{215,5\mu A} = 116\ k\Omega$$

• guadagno differenziale



$i_5 = i_4$
$i_4 \neq i_d$ $\qquad i_d = i_4 + i\,r_{o4}$

$$i_4 = \frac{r_{o4}}{1/g_{m4} + r_{o4}}\, i_d \qquad i_d = i_4 + i\,r_{o4}$$

partitore di corrente tra $1/g_{m4}$ e r_{o4}

$$v_{gs4} = -i_d\left(1/g_{m4} \,//\, r_{o4}\right)$$

$$v_{GS5} = v_{gs4} \longrightarrow i_{d5} = g_{m5}v_{gs5} = g_{m5}v_{gs4} = g_{m5}\left[-i_d\left(1/g_{m4} \,//\, r_{o4}\right)\right]$$

$i_5 = -i_{d5}$

$i_5 = i_4$

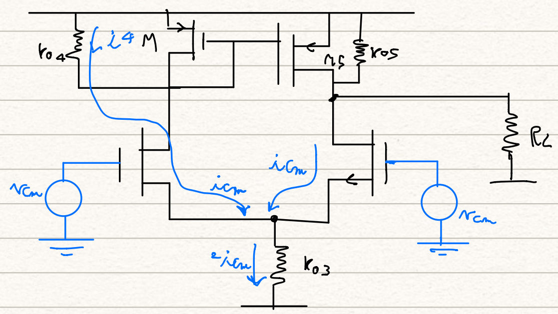
$$i_{TOT} = i_d + i_5 = i_d + i_4 = i_d \underbrace{\left[1 + \frac{r_{o4}}{1/g_{m4} + r_{o4}} \right]}_{\to 2 \text{ pour } r_{o4} \to \infty}$$

$$i_{out} = \frac{r_{o5}}{r_{o5} + R_L} \, i_{TOT}$$

$v_{out} = i_{out} \, R_L // r_{o5}$

$$G_{diff} = \frac{v_{out}}{v_d} = R_L // r_{o5} \; ?$$

• mode commun



$$i_5 = i_4 = i_{cm} \frac{r_{o4}}{r_{o4} + 1/g_{m4}}$$

$$v_{OUT} = i_{TOT} \cdot (r_{o5} // R_L)$$

$i_{TOT} = i_5 - i_{cm}$

$$v_{out} = (r_{o5} // R_L) \left[i_{cm} \frac{r_{o4}}{r_{o4} + 1/g_{m4}} - i_{cm} \right]$$

$G_{cm} \neq 0$

$$\left. \begin{array}{l} G_{cm} = -2{,}25 \cdot 10^{-3} \\ G_{diff} = 2{,}98 \end{array} \right\} CMRR = 1300 \longrightarrow \approx 60\,dB$$