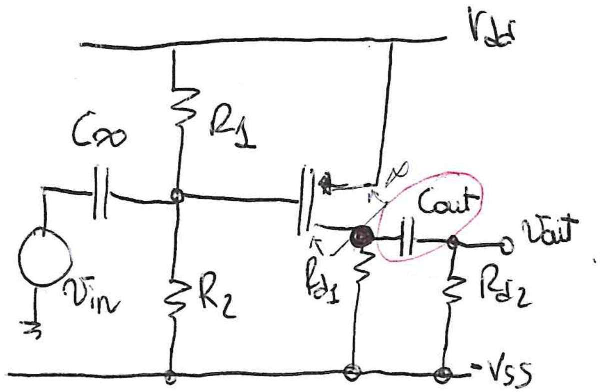
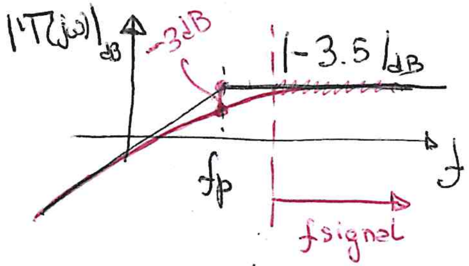
FONDAMENTI DI ELETTRONICA – ESERCITAZIONE 28 MARZO 2024



4. Dim. C_{out} per segnali con $f \in [100\,Hz, 100\,kHz]$

C_{out} zero nell'origine

polo con $\tau_p = C_{out}(R_{d_1} + R_{d_2}) \Rightarrow f_p = \frac{1}{2\pi\tau_p} = \frac{1}{2\pi C_{out}(R_{d_1}+R_{d_2})}$ ← frequenza polo



$$T(s) \triangleq \frac{V_{out}(s)}{V_{in}(s)}$$

$$f_{min\ segnale} = 10 f_p \Rightarrow f_p = \frac{f_{min\ segnale}}{10} = \frac{100\,Hz}{10} = 10\,Hz$$

$$\frac{1}{2\pi C_{out}(R_{d_1}+R_{d_2})} \leq 10\,Hz$$

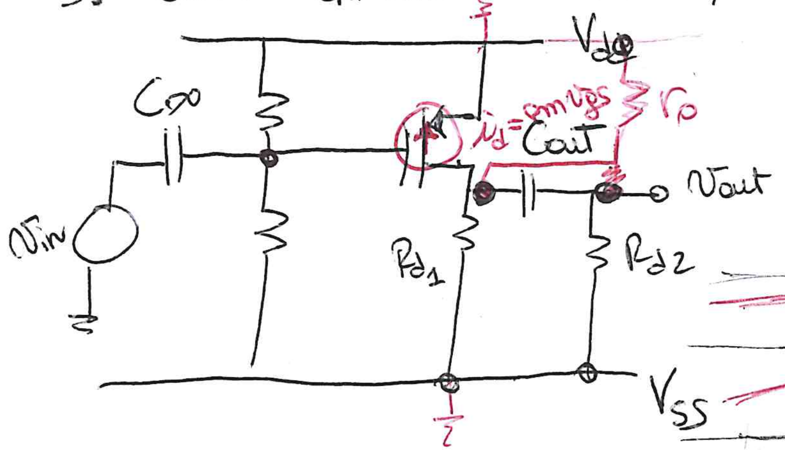
$$C_{out} \geq \frac{1}{2\pi\, 10\,Hz\, \underbrace{(R_{d_1}+R_{d_2})}_{14\,k\Omega}} = 1.14\,\mu F$$

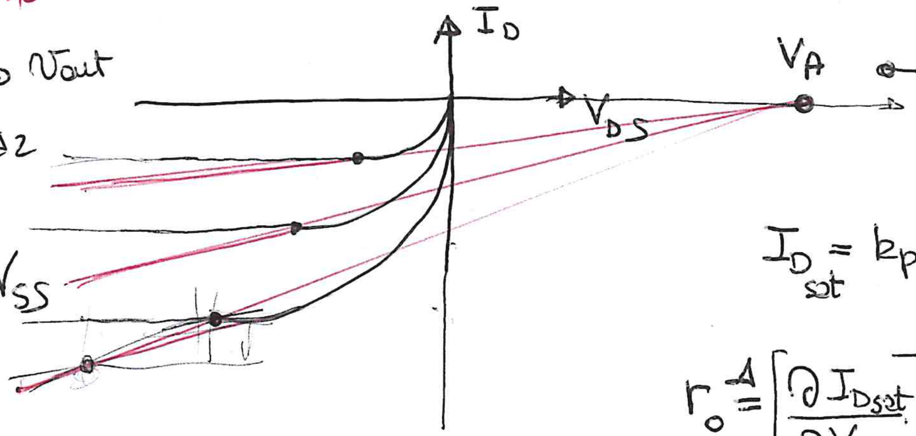
ZERO

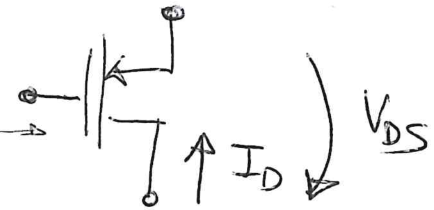
$$\exists\ \bar{s}\ t.c.\ \forall V_{in}(\bar{s}) \neq 0 \quad V_{out}(\bar{s}) = 0$$

3. COME CAMBIA IL GUADAGNO SE $|V_A| = 100V$?

↑ tensione di Early







$$I_{D_{sat}} = k_p (V_{GS} - V_{Tp})^2 (1 + \lambda V_{DS})$$

↑ coeff. di modulazione della lunghezza di canale

$$r_o \triangleq \left[\frac{\partial I_{Dsat}}{\partial V_{DS}}\right]^{-1} = \frac{|V_A|}{I_{Dsat}}$$

$$\lambda = \frac{1}{|V_A|}$$

effetto sul guadagno

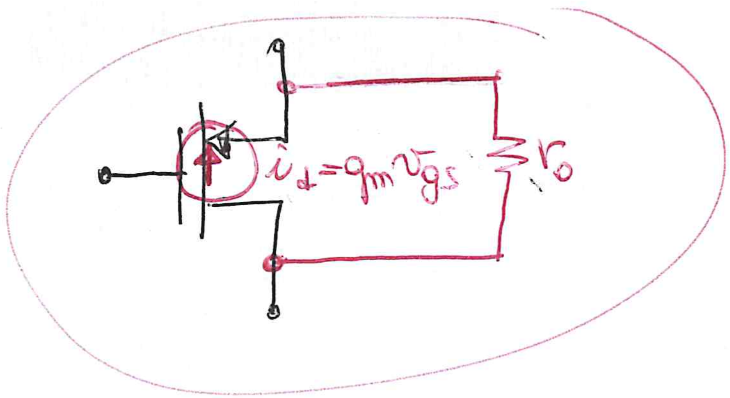
$$v_{out}\Big|_{MF} = -i_d \left[R_{d1} \| R_{d2} \| r_o\right] =$$

$$= -g_m v_{in} \left[R_{d1} \| R_{d2} \| r_o\right] =$$

$$\underbrace{3{,}5k \| 200k}_{3.44\,k\Omega}$$

$$= -3.44$$

$$r_o = \frac{|V_A|}{I} = \frac{100V}{0.5mA} = 200\,k\Omega$$



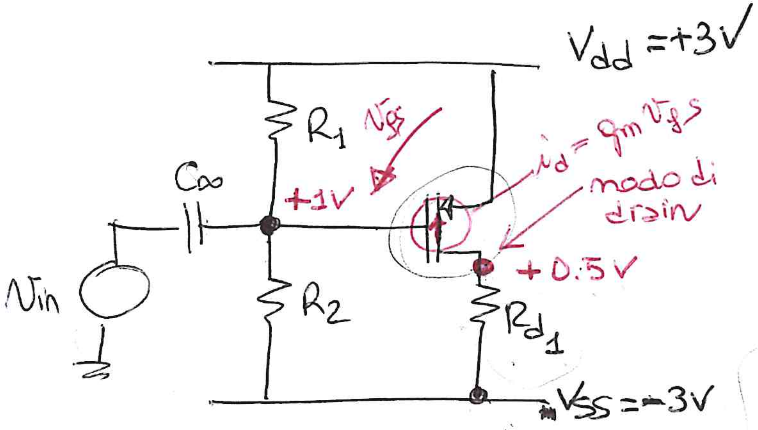
$$\frac{\partial I_{Dsat}}{\partial V_{DS}} = \frac{\partial \left[k_p (V_{GS} - V_{Tp})^2 (1 + \lambda V_{DS})\right]}{\partial V_{DS}}$$

$$= k_p (V_{GS} - V_{Tp})^2 \lambda =$$

$$= k_p (V_{GS} - V_{Tp})^2 \frac{1}{|V_A|} =$$

$$= \frac{I_{Dsat}}{|V_A|}$$

DINAMICA DEL NODO DI DRAIN



DINAMICA: massima escursione di un certo nodo ← scostamento rispetto al punto di lavoro positivo o negativo

$$V_{DC}\Big|_{drain} = +0.5V$$

☆ dinamica negativa: rischio spegnimento pMOS

V_d può scendere fino a V_{SS}

$$\boxed{\Delta V_{out}^{\ominus} = -3.5V}$$

☆ dinamica positiva: pMOS può uscire dalla saturazione

approssimazione zero
Trascuro il segnale!

$V_{GD} \geq V_{Tp}$ ← condiz. di saturaz.

$\Rightarrow V_G = +1V$

$V_G - V_D = V_{Tp} \Rightarrow V_D = V_G - V_{Tp} = +1 - (-1V) = 2V$

$$\Delta V_{out}^{\oplus} = 2V - 0.5V = +1.5V$$

$$v_{drain} = -i_d R_{d_1} = -g_m v_{in} R_{d_1}$$

$v_{in} = \dfrac{-v_{drain}}{g_m R_{d_1}}$ (approx di piccolo segnale)

(considero approssimazione il segnale)

somma di polarizzazione e segnale
↓
$V_{gd} > V_{Tp}$

polarizzazione
↓
$V_{GD} + v_{gd} > V_{Tp}$
↑ segnale

$$V_{GD} + v_{in} - v_d > V_{Tp}$$

$$V_{GD} = 1V - 0.5V = +0.5V$$

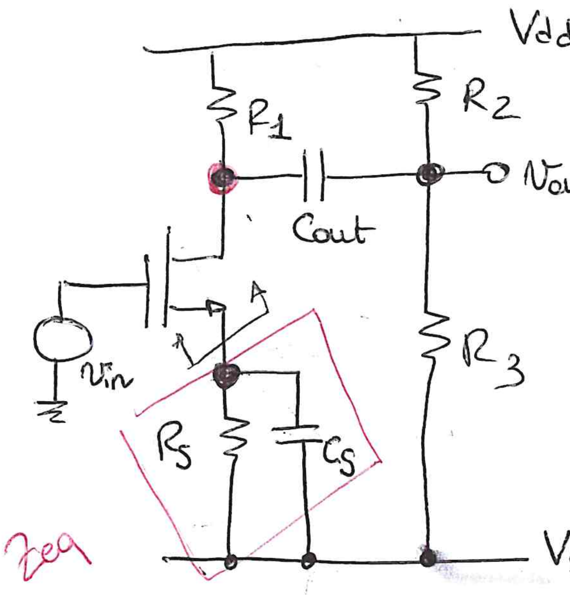
$$V_{GD} - \frac{v_d}{g_m R_{d_1}} - v_d > V_{Tp}$$

$$V_{GD} - v_d\left[\frac{1}{g_m R_{d_1}} + 1\right] > V_{Tp}$$

$$v_d\left[1 + \frac{1}{g_m R_{d_1}}\right] < V_{GD} - V_{Tp} \Rightarrow v_d < \frac{V_{GD} - V_{Tp}}{1 + 1/g_m R_{d_1}} = \frac{+0.5V + 1V}{1 + \frac{1}{7}} = +1.31V$$

$$\boxed{\Delta V_{out}^{\oplus} = +1.31V} \Leftarrow$$

TEMA D'ESAME DEL 14.2.2004 – ES.2



$R_1 = 6k\Omega$

$R_2 = 10k\Omega$

$R_3 = 20k$

$R_S = 4k$

$C_{out} = 4.7\mu F$

$C_S = 470nF$

$k_n = 0.8 mA/V^2$

$V_{Tn} = 0.8V$

$r_0 = \infty$

1. Polarizzazione
2. $\left.\frac{V_{out}}{V_{in}}\right|_{MF}$ (C_{out} chiuso, C_S aperto)
3. $\left.\frac{V_{out}}{V_{in}}\right|_{HF}$ (C_{out} e C_S chiuse)
4. Singolarità introdotte da C_S e C_{out}
5. Se a V_{dd} è sovrapposto un disturbo sinusoidale con freq. 100Hz e amp. 100mV, det. l'ampiezza del disturbo in uscita

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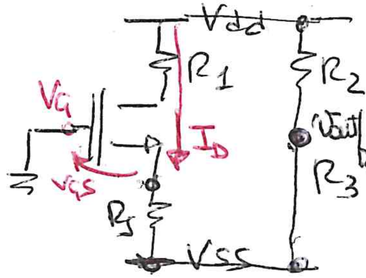
1. Polarizzazione
   - ★ capacità circ. aperti
   - ★ spegniamo v_{in}
   - ★ Hp nMOS saturo



$I = \frac{10V}{30k} = 1/3 \, mA$

$V_G = 0$

$$\begin{cases} I_D = k_n (V_{GS} - V_{Tn})^2 \\ 0 - V_{SS} = V_{GS} + I_D R_S \end{cases}$$

$$-V_{SS} = V_{GS} + k_n R_S (V_{GS} - V_{Tn})^2$$

$$5V = V_{GS} + k_n R_S \left[V_{GS}^2 - 2V_{GS}V_{Tn} + V_{Tn}^2 \right]$$

$\to V_{GS} =$ −0.51V $< V_{Tn}$ fisicamente non accettabile

$\quad\quad\quad\;\;$ +1.8V $> V_{Tn}$ nMOS on

$$I_D = k_n (V_{GS} - V_{Tn})^2 = 0.8 mA/V^2 (1.8V - 0.8V)^2 = 0.8mA$$

$$\Delta V_{R_S} = -1.8V - (-5V) = +3.2V \Rightarrow I_{R_S} = \frac{3.2V}{R_S} = 800\mu A$$ OK

$$V_D = V_{dd} - I_D R_1 = 5V - 0.8mA * 6k\Omega = 200mV$$

$$V_{GD} = 0 - V_D = 0 - 0.2V = -0.2V < V_{Tn}$$ OK MOS saturo

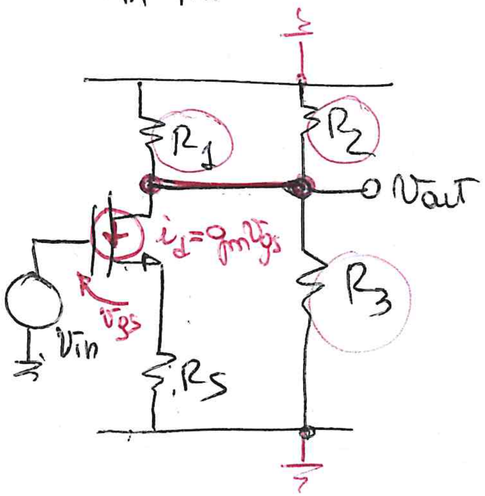
$$V_{out}\big|_{DC} = V_{SS} + \frac{R_3}{R_2 + R_3}(V_{dd} - V_{SS}) = -5V + \frac{20k}{30k} * 10V =$$

$$= +1.67V$$

$$g_m = 2k_n (V_{GS} - V_{Tn}) = 2 * 0.8mA/V^2 * (1.8V - 0.8V) = 1.6mS$$

$\to 1/g_m = 625\Omega$

2. $\left.\frac{v_{out}}{v_{in}}\right|_{MF}$ (Cout chiusa, Cs aperta)



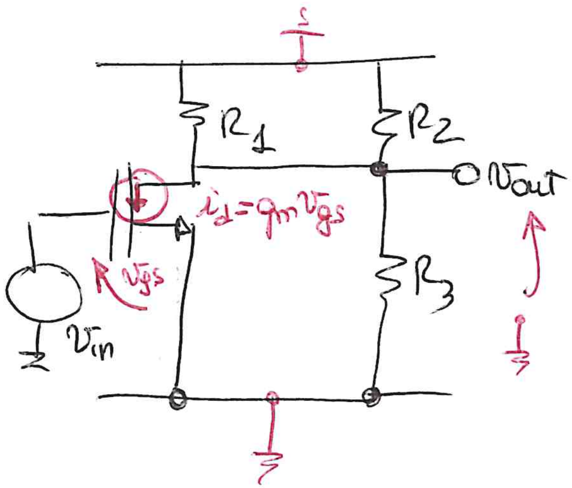
$$v_{out} = -i_d \left(R_1 \| R_2 \| R_3\right)$$

$$i_d = \frac{v_{in}}{1/g_m + R_s}$$

$$\left.\frac{v_{out}}{v_{in}}\right|_{MF} = -\frac{R_1 \| R_2 \| R_3}{1/g_m + R_s} = -\frac{6k \| 10k \| 20k}{625\Omega + 4k\Omega} =$$

$$= -0.69$$

3. $\left.\frac{v_{out}}{v_{in}}\right|_{HF}$ (Cs e Cout corto circ.)



$$v_{out} = -i_d \left(R_1 \| R_2 \| R_3\right) = -g_m v_{gs} \left(R_1 \| R_2 \| R_3\right) =$$

$$= -g_m v_{in} \left(R_1 \| R_2 \| R_3\right)$$

$$\left.\frac{v_{out}}{v_{in}}\right|_{HF} = -g_m \left(R_1 \| R_2 \| R_3\right) = -5.12$$

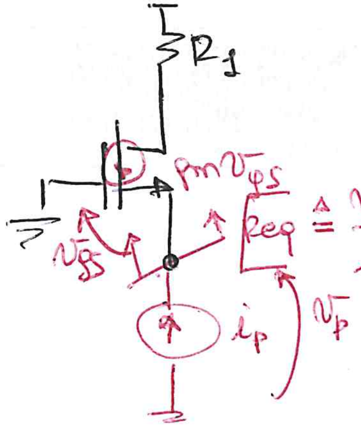
4. singolarità introdotte da C_S e C_{out}

C_{out} : ✱ 1 polo con $\tau_{p_{out}} = C_{out}\left(R_1 + R_2 \| R_3\right) = 59{,}7\,ms$

$\hookrightarrow f_{p_{out}} = \dfrac{1}{2\pi \tau_{p_{out}}} = 2{,}7\,Hz$

✱ 1 zero nell'origine

C_S : ✱ 1 polo con $\tau_{p_S} = C_S\left(R_S \| 1/g_m\right) = 254\,\mu s \Rightarrow f_{p_S} = \dfrac{1}{2\pi \tau_{p_S}} = 626\,Hz$



$R_{eq} \triangleq \dfrac{v_p}{i_p} = \dfrac{+v_{gs}}{+g_m v_{gs}} = \boxed{\dfrac{1}{g_m}}$

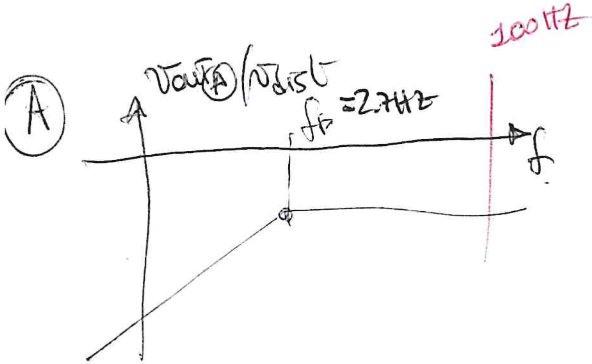
$$Z_{eq}(s) = \frac{R_S}{1 + sC_SR_S} \longrightarrow \infty$$

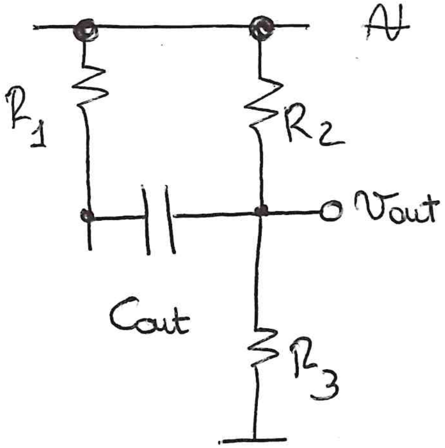
✱ 1 zero

$1 + sC_SR_S \to 0$

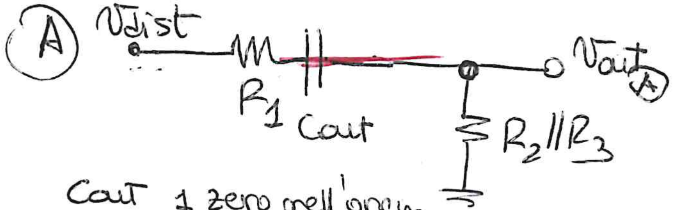
$\hookrightarrow s = -\dfrac{1}{C_SR_S} = -\dfrac{1}{\tau_z} \Rightarrow \tau_z = C_SR_S = 1{,}88\,ms$

$\hookrightarrow f_{z_S} \simeq 85\,Hz$



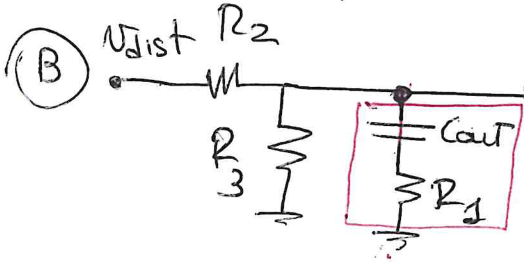


sovrapp. ⇒ effetti



Cout 1 zero nell'origine

1 polo $\tau_p = C_{out}(R_1 + R_2 \| R_3) \rightarrow 2.7Hz$

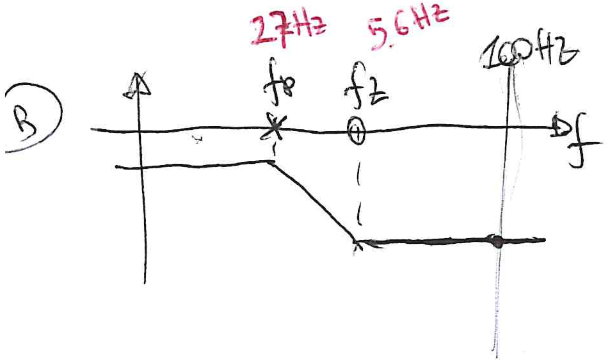


$Z_{eq}(s) = \frac{1}{sC_{out}} + R_1$

polo $\tau_p = C_{out}(R_1 + R_2 \| R_3) \Rightarrow f_p = 2.7Hz$

zero se $Z_{eq}(s) = 0 \Rightarrow R_1 + \frac{1}{sC_{out}} = 0 \Rightarrow \tau_z = C_{out} R_1$

$\rightarrow f_z = 5.6Hz$



$$V_{out}\Big|_{dist} = V_{out(A)} + V_{out(B)}$$

$$V_{out(A)} = \frac{R_2 \| R_3}{R_1 + R_2 \| R_3} v_{dist} = \frac{6.67k}{6.67k + 6k} \cdot 100mV = 52.6mV$$

$$V_{out(B)} = \frac{R_1 \| R_3}{R_2 + R_1 \| R_3} v_{dist} = \frac{4.6k}{10k + 4.6k} \cdot 100mV = 31.5mV$$

$$V_{out}\Big|_{dist} = V_{out(A)} + V_{out(B)} = 84.1mV$$