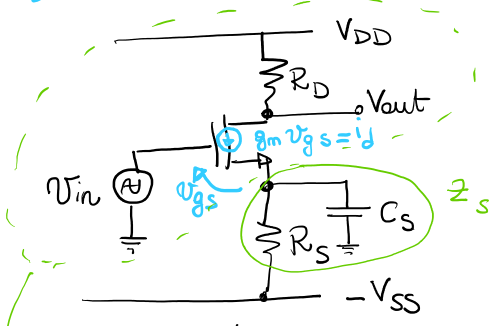
Lezione 9d: dimensionamento capacita' di bypass, errore di linearita' source degenerato, efffetto resistenza di uscita

lunedì 20 aprile 2020 10:35

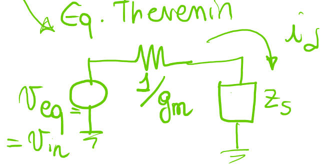
DIMENSIONAMENTO DELLA CAPACITÀ DI BYPASS



$$Z_s(s) = \frac{R_s}{1 + sC_sR_s}$$

$$v_{in} = v_{gs} + i_d Z_s$$

Eq. Thevenin



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

$$V_{out}(s) = -i_d R_d = -v_{in}(s) \frac{R_d}{1/g_m + \frac{R_s}{1 + sC_sR_s}}$$

Funz. di trasferimento

$$\Gamma(s) \triangleq \frac{V_{out}(s)}{V_{in}(s)} = -\frac{R_d}{1/g_m + \frac{R_s}{1 + sC_sR_s}} =$$

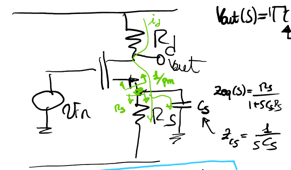
$$= \frac{-g_m R_d (1 + sC_sR_s)}{1 + sC_sR_s + g_m R_s} = -\frac{g_m R_d (1 + sC_sR_s)}{(1 + g_m R_s)\left(1 + \frac{sC_sR_s}{1 + g_mR_s}\right)} =$$

$$= -\underbrace{\frac{g_m R_d}{1 + g_m R_s}}_{\text{TRASF. IN DC}} \underbrace{\frac{1 + sC_sR_s}{1 + sC_s(R_s \parallel 1/g_m)}}_{\text{TERMINE IN S}}$$

C_s : * polo $\tau_p = C_s (R_s \parallel 1/g_m)$

* zero $\tau_z = C_s R_s$

$V_{out}(s) = \Gamma(s)\, V_{in}(s)$



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

$V_{out}(s) = 0$ sse $i_d(s) = 0$

$i_d = g_m v_{gs}(s)$ $\quad g_m \neq 0 \Rightarrow v_{gs}(s) = 0$

$Z_{eq}(s) = \frac{R_s}{1 + sC_sR_s} \longrightarrow \infty$

$\hookrightarrow 1 + sC_sR_s = 0$

$s = -\frac{1}{C_sR_s} = -\frac{1}{\tau_z}$

Calcolo della funzione di trasferimento per ispezione

- $\Gamma(0)$ Trasf. in DC

$$\Gamma(0) = \frac{-R_d}{1/g_m + R_s} = -\frac{g_m R_d}{1 + g_m R_s}$$

- singolarità di C_s

  * polo $\tau_p = C_s (R_s \parallel 1/g_m) \rightarrow \omega_p = \frac{1}{\tau_p} = \frac{1}{C_s (R_s \parallel 1/g_m)}$

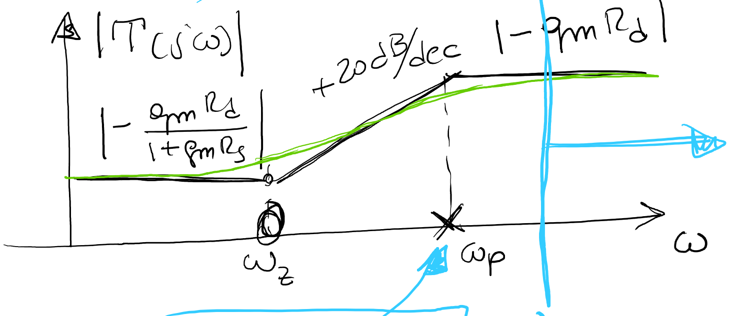
  * zero $\tau_z = C_s R_s \rightarrow \omega_z = \frac{1}{\tau_z} = \frac{1}{C_s R_s}$

$$\Gamma(\infty) \simeq -\frac{g_m R_d}{1 + g_m R_s} \frac{\cancel{s} C_s R_s}{\cancel{s} \cancel{C_s} (R_s \parallel 1/g_m)} =$$

$$= -\frac{g_m R_d}{1 + g_m R_s} \frac{\cancel{R_s}}{\frac{\cancel{R_s}\, 1/g_m}{1/g_m + R_s}} =$$

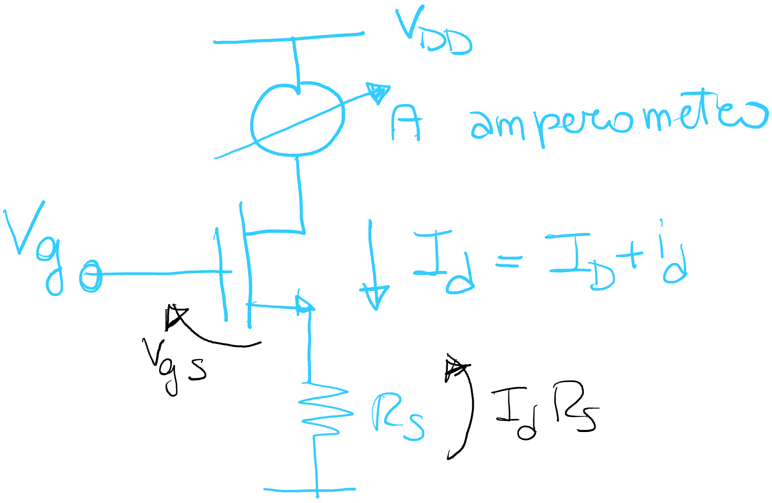
$$= -\frac{1}{1+g_m R_s} \cdots \frac{R_s \, 1/g_m}{1/g_m + R_s}$$

$$= -\frac{g_m R_d}{1+g_m R_s}\,(1+g_m R_s) = -g_m R_d$$



$\omega_p = \frac{1}{10}\,\omega_{segnale\ min.}$ (ω segnale minima)

ERRORE DI LINEARITÀ IN STADIO SOURCE DEGENERATO



$$I_d = k_n\left[V_{gs} - V_{Tn}\right]^2 = k_n\left[V_G - V_S + v_g - v_s - V_{Tn}\right]^2$$

$$= k_n\left[(V_{GS} - V_{Tn}) + v_{gs}\right]^2 =$$

$$= \underbrace{k_n (V_{GS} - V_{Tn})^2}_{I_D} + \underbrace{2k_n (V_{GS} - V_{Tn})\, v_{gs} + k_n v_{gs}^2}_{i_d}$$

$$\begin{cases} i_d = g_m v_{gs} + k_n v_{gs}^2 \\ v_s = i_d R_s \end{cases}$$

$$i_d = g_m (v_g - i_d R_s) + k_n \left[v_g - i_d R_s\right]^2$$

$\Downarrow$

$$\Downarrow$$

$$k_n R_s^2 i_d^2 - i_d\left(1+g_m R_s + 2 k_n R_s v_g\right) + g_m v_g + k_n v_g^2 = 0$$

$$a x^2 + b x + c = 0$$

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

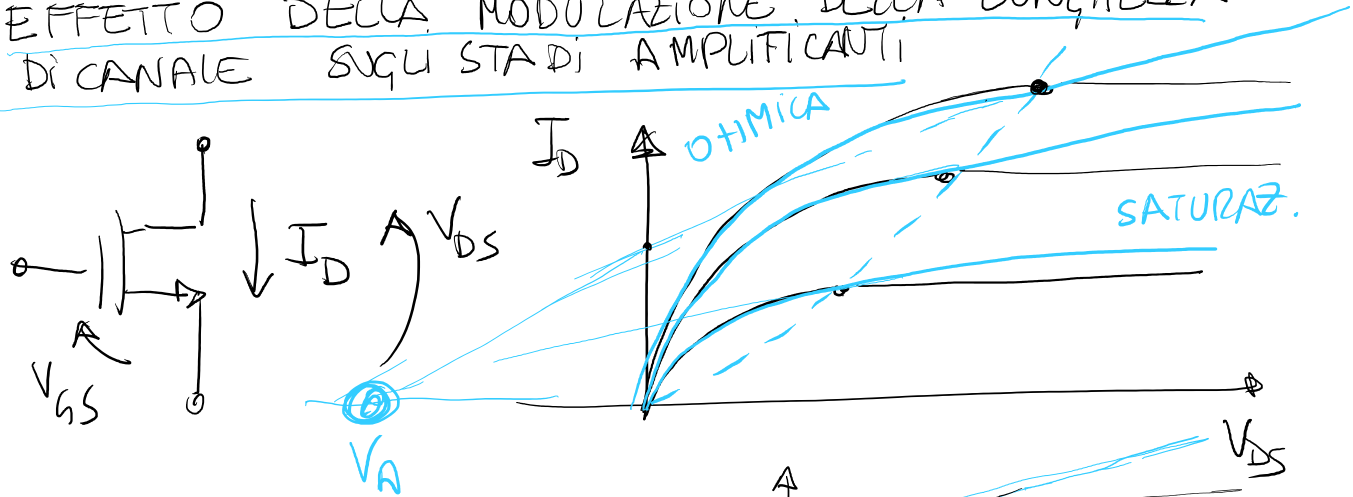
$$(1+x)^{1/2} \simeq 1 + \frac{x}{2} - \frac{1}{2}\frac{x^2}{4} + \dots$$

$$\Downarrow$$

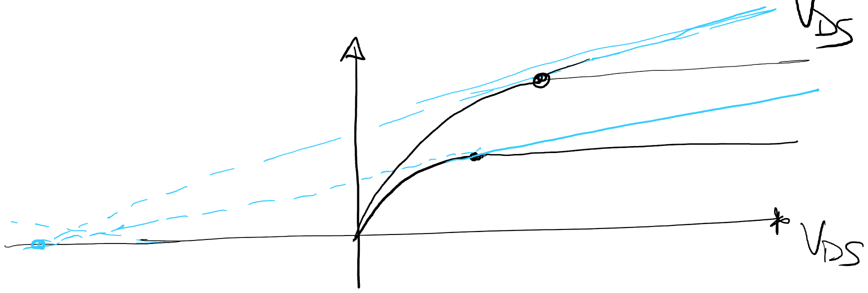
ERRORE DI LINEARITÀ STADIO SOURCE DEGENERATO

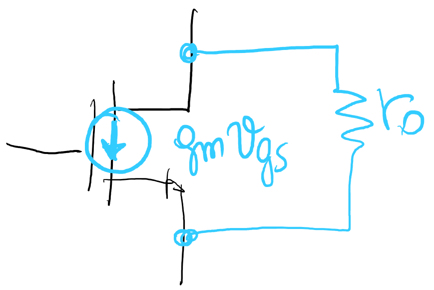
$$\varepsilon = \frac{k_n v_g^2 / (1+g_m R_s)^3}{\frac{g_m v_g}{1+g_m R_s}} = \underbrace{\frac{v_g}{1+g_m R_s}}_{v_{gs}} \frac{1}{2(V_{GS}-V_{Tn})} \frac{1}{1+g_m R_s}$$

EFFETTO DELLA MODULAZIONE DELLA LUNGHEZZA DI CANALE SUGLI STADI AMPLIFICANTI

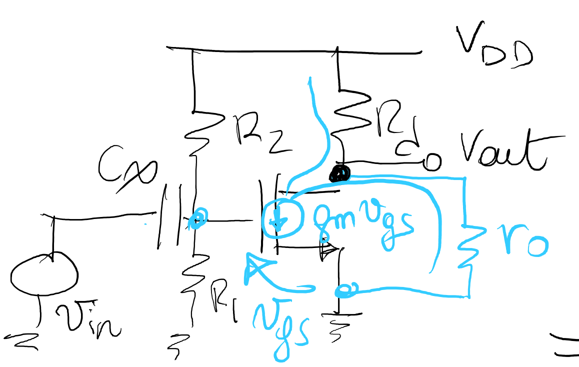


$$r_0 = \frac{|V_A|}{I_D}$$





$$i_d = g_m v_{gs} = g_m v_{in}$$



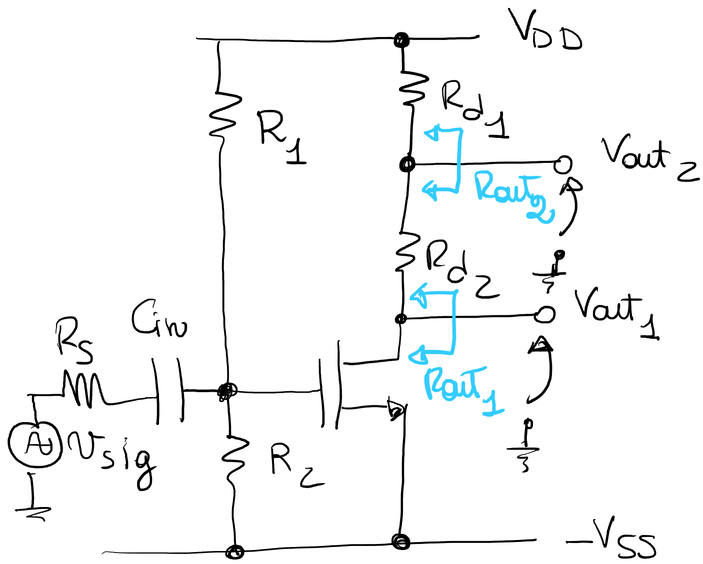
$i_d = g_m v_{gs} = g_m v_{in}$

$V_{out} = - i_d \, R_d \parallel r_o =$

$= - g_m R_d \parallel r_o \; v_{in} \Rightarrow$

$$\Rightarrow \frac{V_{out}}{V_{in}} = - g_m R_d \parallel r_o$$

ESERCIZIO: analisi amplificatore nMOS in configurazione source comune (source a massa)



$V_{T_n} = 0{,}5V$

$V_{DD} = +5V$

$-V_{SS} = -5V$

$k_n = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} =$

$= 1 mA/V^2$

$R_2 = 150 k\Omega$

$R_1 = 850 k\Omega$

$|\ _1 = 2k\Omega$

$= 4k$

$R_S = 200\Omega$

(a) Polarizzazione dello stadio

(b) Guadagno di piccolo segnale $\frac{v_{out_1}}{v_{sig}}$ e $\frac{v_{out_2}}{v_{sig}}$ (a media frequenza, Cin corto circuito)

(c) Dimensionamento di Cin per amplificare segnali nella banda [1kHz, 50kHz]

(d) Resistenze R_{out_1} e R_{out_2}

(e) Errore di linearità se v_s è un segnale sinusoidale di ampiezza 100 mV e frequenza 30 kHz

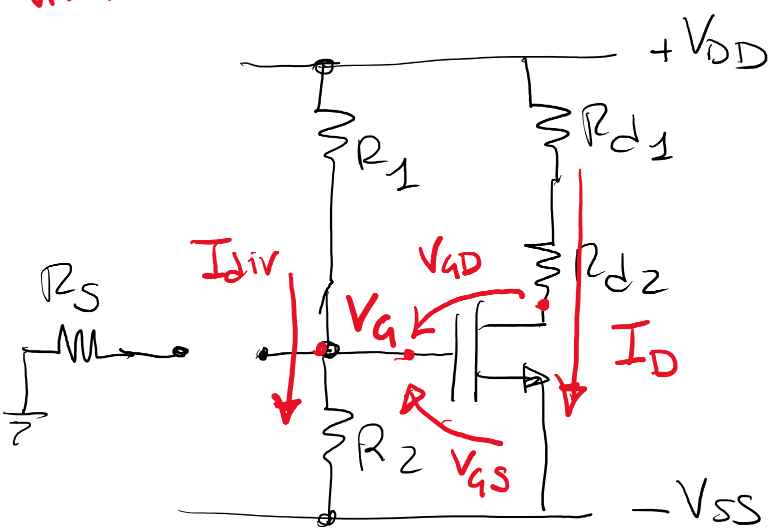
(a) POLARIZZAZIONE

- spegnere i generatori di segnale

② POLARIZZAZIONE

1. spegnere i generatori di segnale
2. i condensatori sono circuiti aperti
3. **Hp** che il MOS sia saturo

VA VERIFICATA!



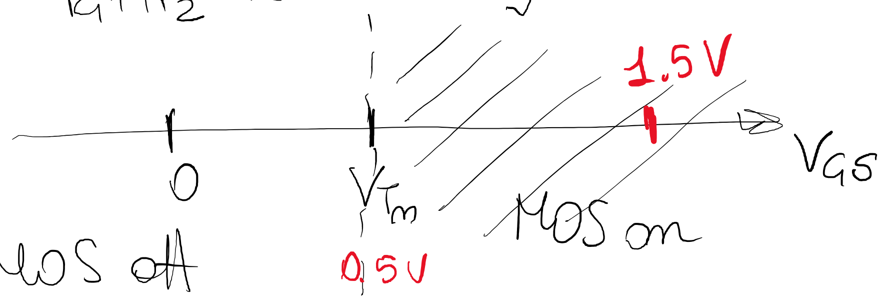
CIRCUITO PER LA POLARIZZAZIONE

$$V_G = -V_{SS} + \frac{R_2}{R_1+R_2}\left[V_{DD} - (-V_{SS})\right] =$$

$$= -5V + \frac{150k}{\underbrace{850k + 150k}_{1M}} 10V = -5V + 1.5V = -3.5V$$

$$I_{div} = \frac{V_{DD} - (-V_{SS})}{R_1 + R_2} = \frac{10V}{1M\Omega} = 10\mu A$$

$$V_{GS} = \frac{R_2}{R_1+R_2}\left[V_{DD} - (-V_{SS})\right] = 1.5V > V_{Tn} \text{ ok MOS on}$$



sotto l'hp che il MOS sia saturo

$$I_D = k_n (V_{GS} - V_{Tn})^2 = 1\,mA/V^2 \,(1.5V - 0.5V)^2 =$$

$$I_D = k_n (V_{GS} - V_{Tn})^2 = 1\,mA/V^2\,(1.5V - 0.5V)^2 = 1\,mA$$

$$V_D = V_{DD} - I_D (R_{d_1} + R_{d_2}) = 5V - 1mA \times (2k + 4k) = -1V$$

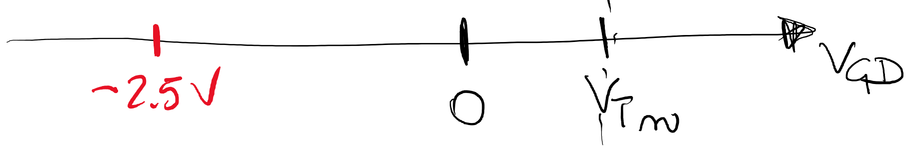
⇓

$$V_{GD} = -3.5V - (-1V) = -3.5V + 1V = -2.5V < V_{Tn}$$

$\stackrel{\Delta}{=} V_G - V_D$

↑ saturo

pinch-off lato drain | no pinch off al drain → ohmico



↳ MOS è saturo $\begin{cases} \text{MOS on} \\ V_{GD} < V_{Tn} \end{cases}$

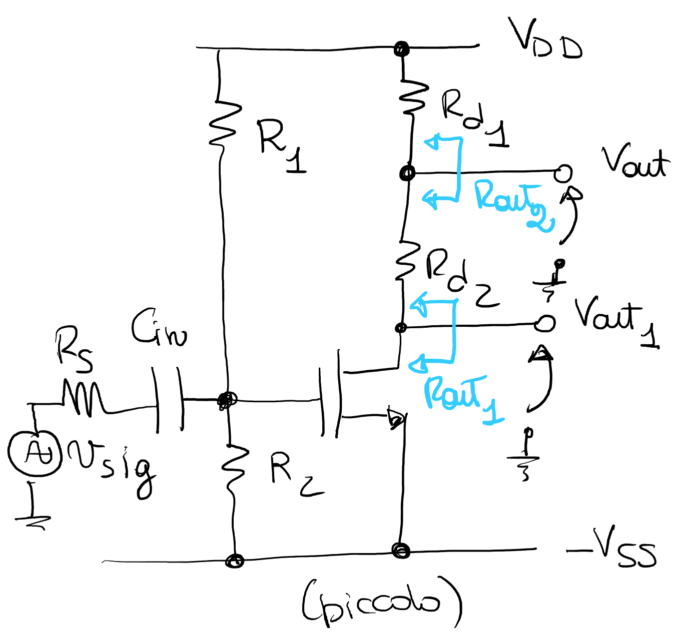
⇓

$I_D = 1\,mA$ ok

transconduttanza $g_m = 2k_n (V_{GS} - V_{Tn}) = 2 \times 1\,mA/V^2\,(1.5V - 0.5V) = 2\,mA/V = 2\,mS$

$1/g_m = 500\,\Omega$

(b) v_{out2}/v_{sig} ? v_{out1}/v_{sig} ?



$V_{Tn} = 0.5V$

$V_{DD} = +5V$

$-V_{SS} = -5V$

$k_n = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} = 1\,mA/V^2$

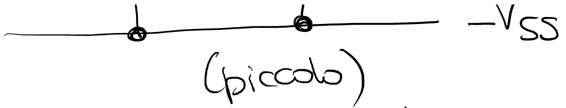
$R_2 = 150\,k\Omega$

$R_1 = 850\,k\Omega$

$R_{d_1} = 2\,k\Omega$

$R_{d_2} = 4k$

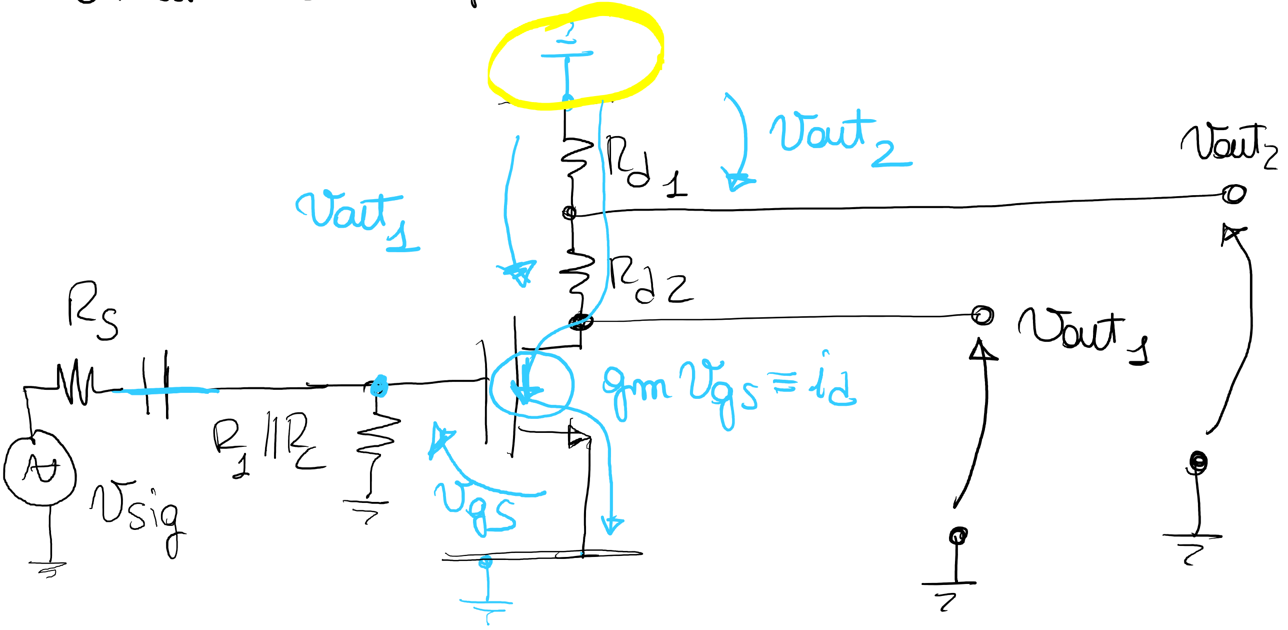
$R_S = 200\,\Omega$



$R_{d2} = 4k$

$R_S = 200\,\Omega$

Circuito su segnale:



$$v_{gs} = \frac{R_1 \| R_2}{R_S + R_1 \| R_2}\, v_{sig}$$

$$i_d = g_m v_{gs} = g_m \frac{R_1 \| R_2}{R_S + R_1 \| R_2}\, v_{sig}$$

$$v_{out_1} = - i_d \left(R_{d_1} + R_{d_2}\right) = - g_m \left(R_{d_1} + R_{d_2}\right) \frac{R_1 \| R_2}{R_S + R_1 \| R_2}\, v_{sig}$$

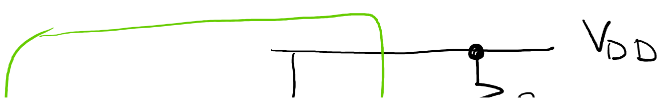
$$\frac{v_{out_1}}{v_{sig}} = - g_m \left(R_{d_1} + R_{d_2}\right) \frac{R_1 \| R_2}{R_S + R_1 \| R_2} = -11.98 \simeq -12 \quad \text{OK}$$

$\frac{R_1 \| R_2}{R_S + R_1 \| R_2} \leftarrow 0.998$

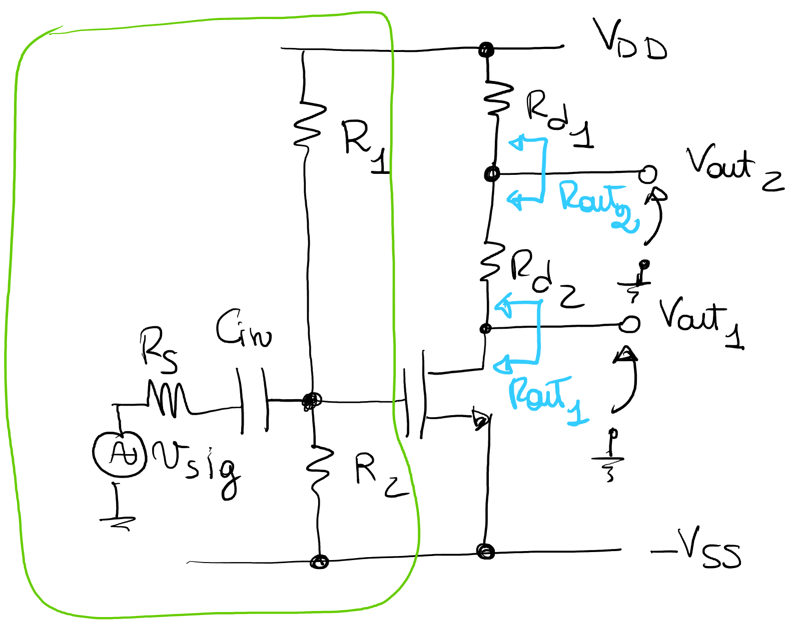
$$R_1 \| R_2 = 150k \| 850k = 127.5\,k\Omega$$

$$v_{out_2} = - i_d R_{d_1} \Rightarrow \frac{v_{out_2}}{v_{sig}} = - g_m R_{d_1} \frac{R_1 \| R_2}{R_S + R_1 \| R_2} = -3.99$$

(c) DIMENSIONAMENTO Gn



$V_{Tn} = 0.5\,V$



$V_{Tn} = 0{,}5\,V$

$V_{DD} = +5\,V$

$-V_{SS} = -5\,V$

$k_n = \frac{1}{2}\mu_n C_{ox}\frac{W}{L} = 1\,mA/V^2$

$R_2 = 150\,k\Omega$

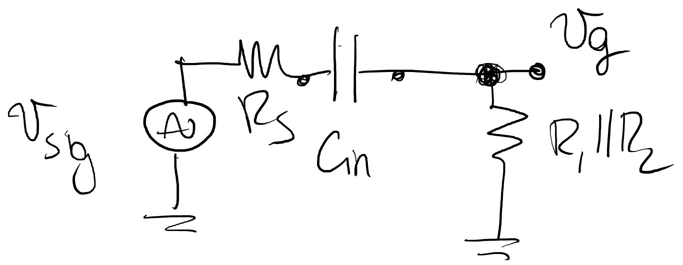
$R_1 = 850\,k\Omega$

$R_{d_1} = 2\,k\Omega$

$R_{d_2} = 4\,k$

$R_S = 200\,\Omega$

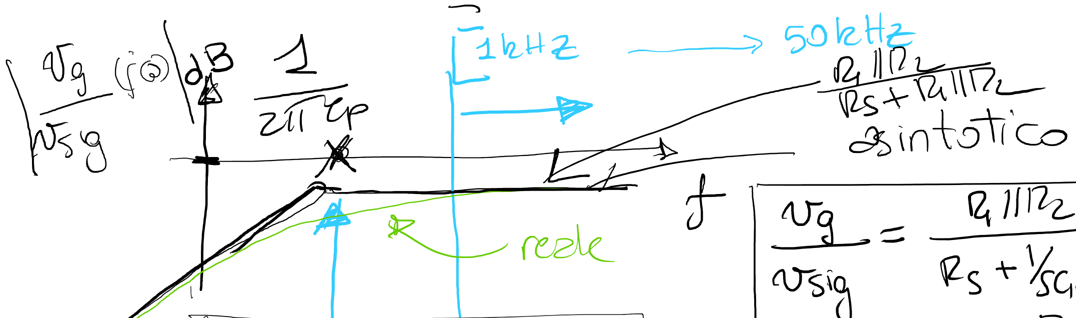
$f_{sig} \in [1\,kHz, 50\,kHz]$



C_{in} polo con $\tau_p = C_{in}(R_S + R_1 \| R_2)$

↳ $f_P = \frac{1}{2\pi\tau_p}$,

C_{in} zero nell'origine



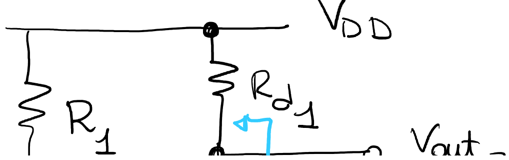
$f_P = \frac{f_{sig\,min}}{10}$

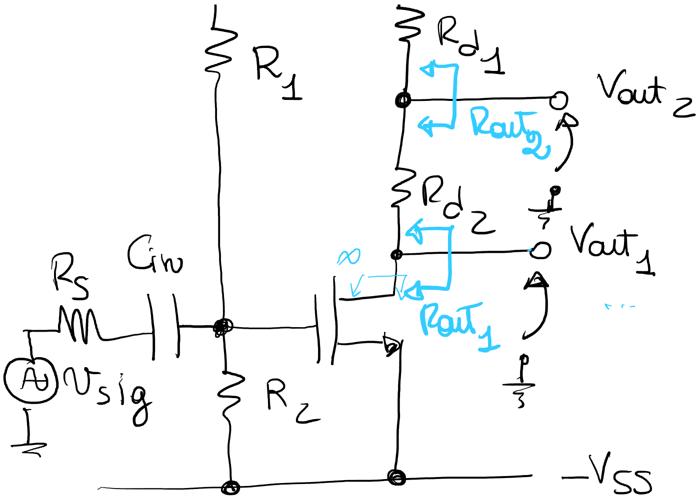
$$\frac{v_g}{v_{sig}} = \frac{R_1 \| R_2}{R_S + \frac{1}{sC_{in}} + R_1 \| R_2} = \frac{sC_{in} R_1 \| R_2}{1 + sC_{in}(R_S + R_1 \| R_2)}$$

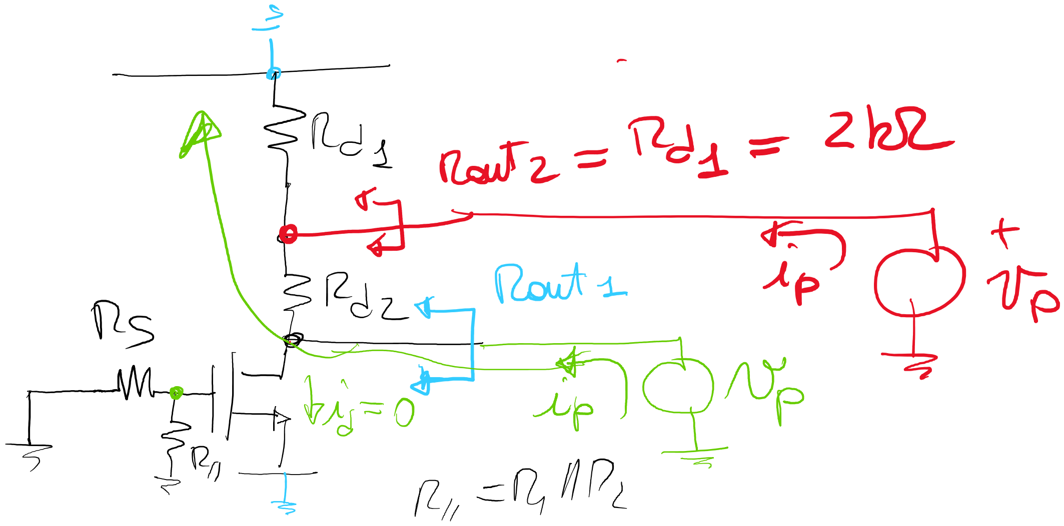
$$\frac{1}{2\pi C_{in}(R_S + R_1 \| R_2)} \leq \frac{1\,kHz}{10}$$

$$C_{in} \geq \frac{1}{2\pi(R_S + R_1 \| R_2) \cdot 100\,Hz} = 12{,}5\,mF$$

(d) Calcolo R_{out_1} e R_{out_2}







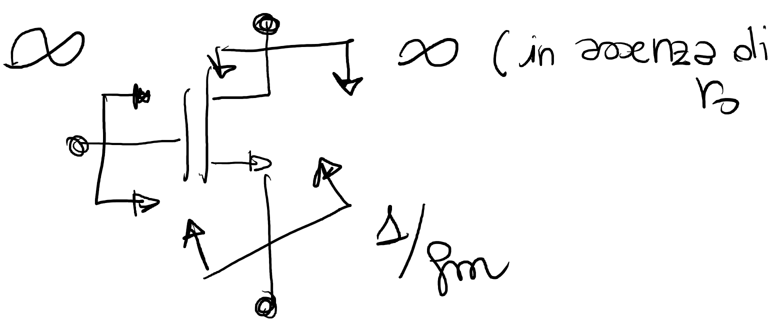
$$R_{out\,2} = R_{d_1} = 2\,k\Omega$$

$$R_{//} = R_1 \,//\, R_2$$

$$R_{out_1} \triangleq \frac{v_p}{i_p} = R_{d_1} + R_{d_2} = 6\,k\Omega$$

$$i_p = \frac{v_p}{R_{d_1} + R_{d_2}}$$

RESISTENZE VISTE AI MORSETTI DI UN TRANSISTOR



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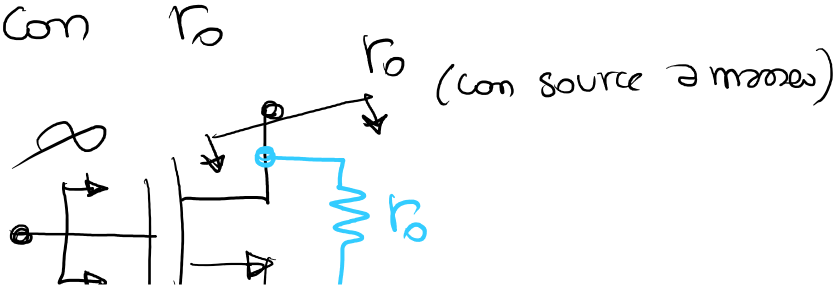
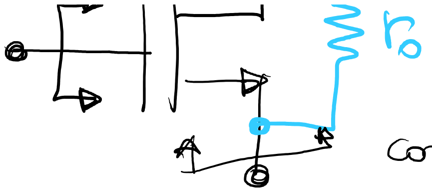
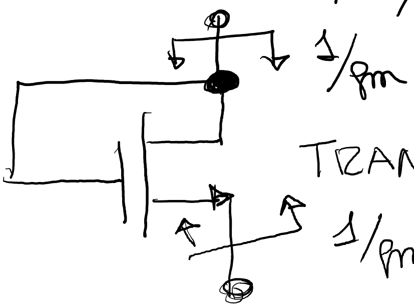
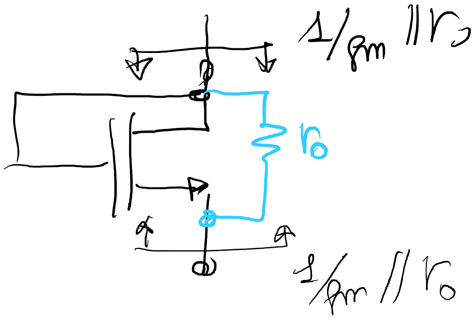




con drain a massa

$$r_o \parallel 1/g_m \simeq 1/g_m$$

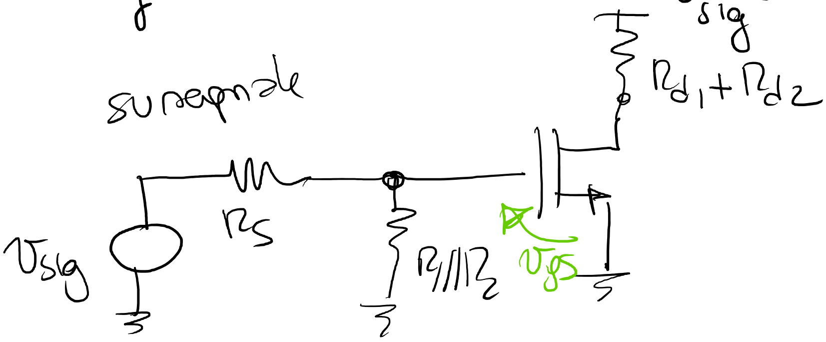




e) errore di linearità

$$v_{sig} = 100mV \sin(2\pi f_{sig} t) \qquad f_{sig} = 30kHz$$

su segnale



$$v_{gs} = \frac{R_1 \parallel R_2}{R_S + R_1 \parallel R_2} v_{sig} = \frac{127.5 k\Omega}{127.7 k\Omega} 100mV$$

$$\varepsilon = \frac{v_{gs}}{2(V_{GS}-V_T)} = \frac{99.8 mV}{2(1.5V - 0.5V)} =$$

$$= 5\%$$

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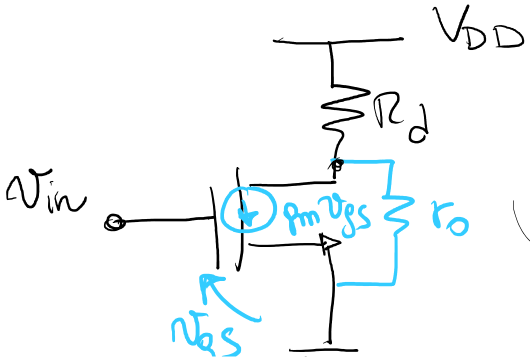
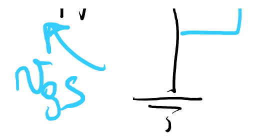
circuito su segnale

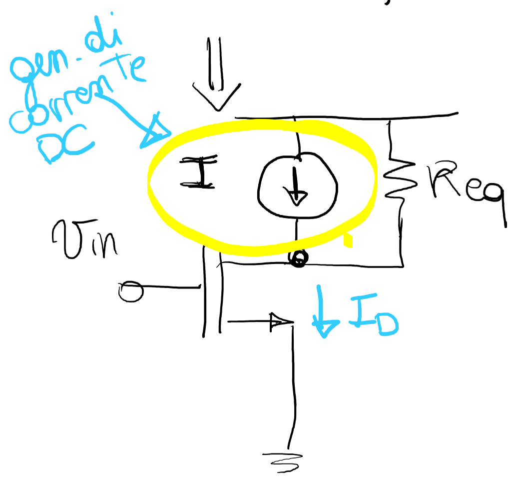


$$|G_{MAX}| = g_m r_o$$

$$G = -g_m r_o \parallel R_d$$



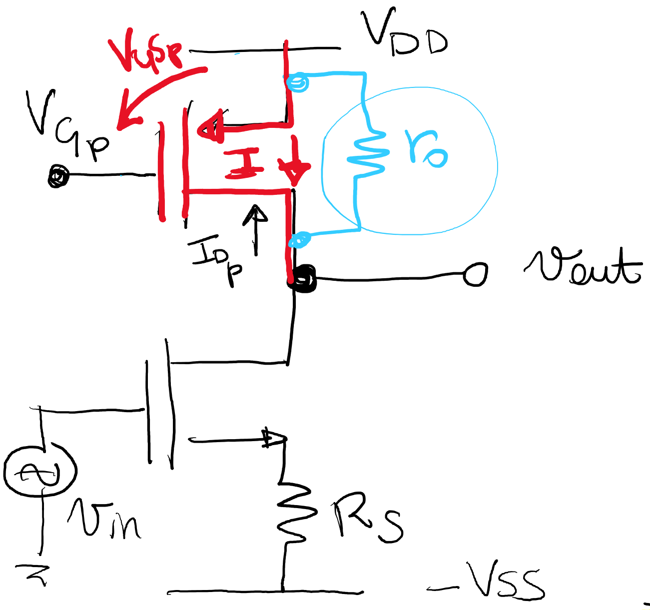
$$G = -g_m \, r_o \,//\, R_d$$



* polarizzazione

$I_D \simeq I$ (R_{eq} molto grande)

* segnale



STADIO A TRANSISTORE CON CARICO ATTIVO