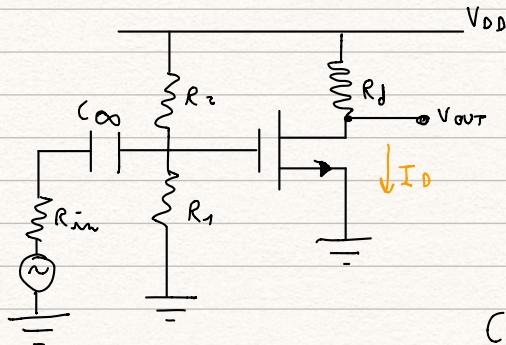


STADIO SOURCE A MASSA:



V_{DD} generatore di tensione DC

V_{in} generatore di segnale

$$C_\infty \left\{ \begin{array}{l} |z| = \frac{1}{w C_\infty} = \infty \quad w=0 \text{ in DC} \\ |z| = \frac{1}{w C_\infty} = 0 \quad w \neq 0 \end{array} \right.$$

(A) POLARIZZAZIONE: tensioni a tutti i nodi e corrente in tutti i rami

1: capacità circuiti spenti perché in DC

2: generatori di segnali spenti

3: $|H_p|$ nos spenti in saturazione
da verificare

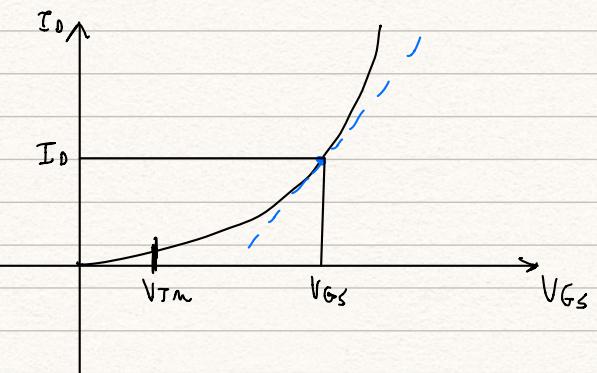
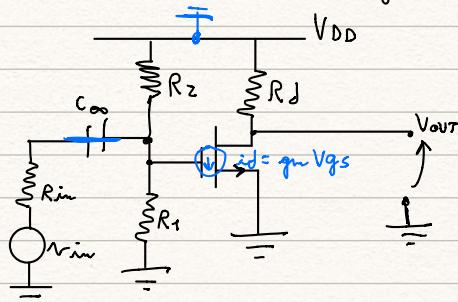
$$V_{GS} = \frac{R_1}{R_1 + R_2} V_{DD} \longrightarrow I_D = k_n (V_{GS} - V_{Tn})^2$$

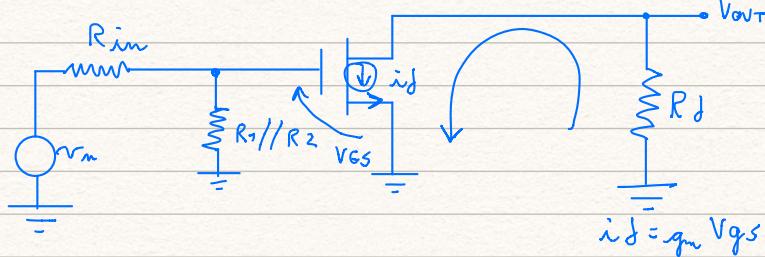
$$V_D = V_{out} = V_{DD} - I_D R_D : \quad I_{D\text{dir}} = \frac{V_{DD}}{R_1 + R_2}$$

$$V_{GD} = V_G - V_D \quad \text{se } V_{GD} < V_{Tn} \longrightarrow \text{OK nos natur}$$

$$g_m = 2 k_n (V_{GS} - V_{Tn})$$

(B) ANALISI su (piccolo) segnale





$$V_{gs} = \frac{R_1 // R_2}{R_{in} + R_1 // R_2} \rightarrow i_d = g_m V_{gs} \quad V_{gs} \ll (V_{gs} - V_{Tm})$$

$$V_{out} = -i_d R_D = -g_m R_D V_{gs} = -g_m R_D \frac{R_1 // R_2}{R_{in} + R_1 // R_2} V_{in}$$

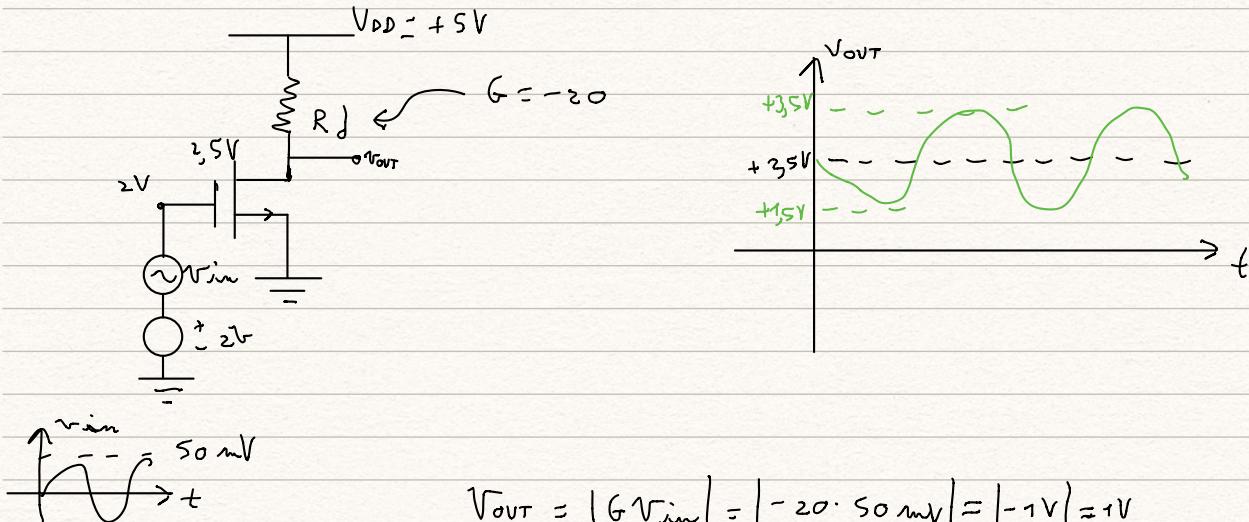
$$G = \frac{V_{out}}{V_{in}} = -g_m R_D \underbrace{\frac{R_1 // R_2}{R_{in} + R_1 // R_2}}_{\text{portione in ingresso}}$$

• Stadio invertente

ERRORE DI LINEARITÀ:

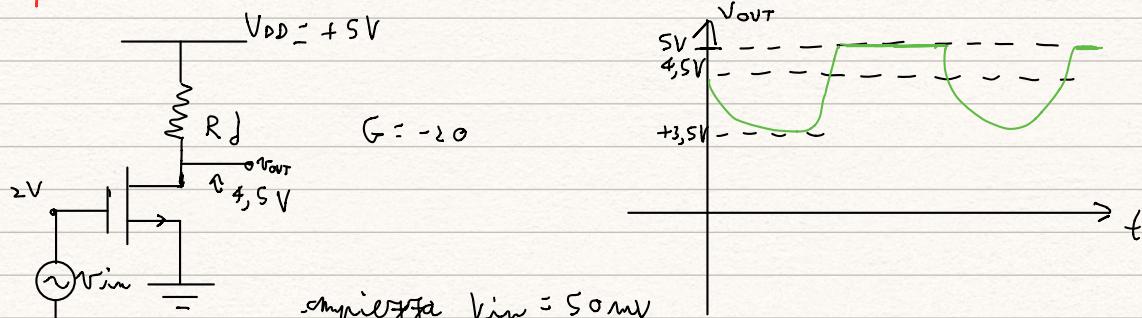
$$\epsilon = \frac{V_{gs}}{2(V_{gs} - V_{Tm})}$$

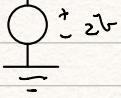
esempio:



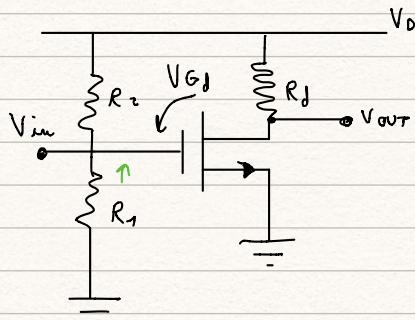
$$V_{out} = |G V_{in}| = |-20 \cdot 50 \text{ mV}| = |-1 \text{ V}| = 1 \text{ V}$$

esempio 2:





DINAMICA DI USCITA: Massima variazione positiva o negativa del nodo di uscita, rispetto al punto di lavoro perché i transistori operano nella corretta zona di funzionamento



V_{out} può salire fino a V_{DD}

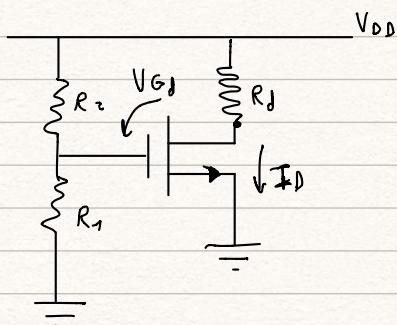
$V_{out} < V_{DD}$

$$\Delta V_{out} = V_{DD} - V_{out} \quad \text{in polarizzazione}$$

$V_{GS} < V_{Tm}$ per garantire la saturazione del mos

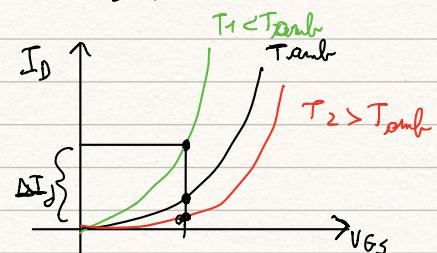
$$V_{GS} = V_G + V_g - \underbrace{(V_D + V_f)}_{V_f} = V_G + V_g - V_D - V_f < V_{Tm}$$

SENSIBILITÀ ALLE VARIAZIONI DEI PARAMETRI DEL MOS DELLA POLARIZZAZIONE DI UNO STADIO SOURCE A MASSA



$$I_D = K_m (V_{GS} - V_{Tm})^2$$

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

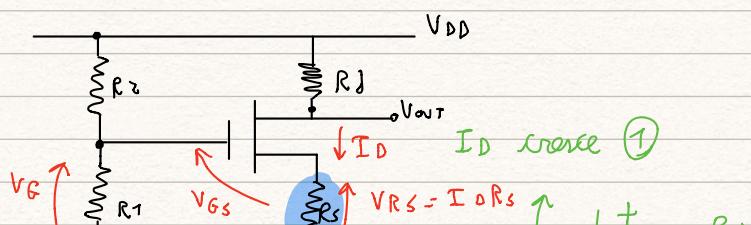


$$1\% / {C^\circ}$$

$$\Delta I_D = \Delta K_m \left(V_{GS} - V_{Tm} \right)^2 \cdot K_m \quad \text{ID}$$

$$\frac{\Delta I_D}{I_D} = \frac{\Delta K_m}{K_m}$$

STADIO DI DEGENERAZIONE DI SOURCE:





I scaduta su RS cresce (2)

A) POLARIZZAZIONE

$$I_D = K_n (V_{GS} - V_{Tn})^2$$

(sotto le HP che non saturano)

$$V_G = \frac{R_1}{R_1 + R_2} V_{DD}$$

$V_{GS} > V_{Tn}$ accresce

$V_{GD} < V_{Tn}$ pinch off - lato drain

$$\begin{cases} I_D = K_n (V_{GS} - V_{Tn})^2 \\ V_G = V_{GS} + I_D R_S \end{cases} \rightarrow I_D, V_{GS} \rightarrow \text{hanno una soluzione finitamente possibile}$$

$$V_{OUT} = V_D = V_{DD} - I_D R_D$$

$$V_{GD} < V_{Tn} ? \quad \text{SI} \rightarrow \text{OK MOS SATURATO}$$

$$I_D = K_n (V_{GS} - V_{Tn})^2$$

V_{GS} dipende da K_n

$$V_{GS} = V_G - I_D R_S$$

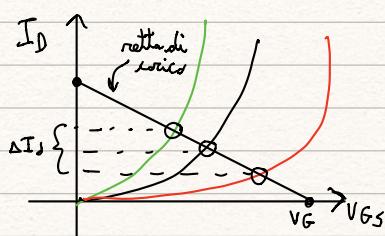
$$\Delta I_D = \Delta K_n [V_{GS}(K_n) - V_{Tn}]^2 + K_n 2(V_{GS} - V_{Tn}) \Delta V_{GS}$$

$$\Delta V_{GS} = -\Delta I_D R_S$$

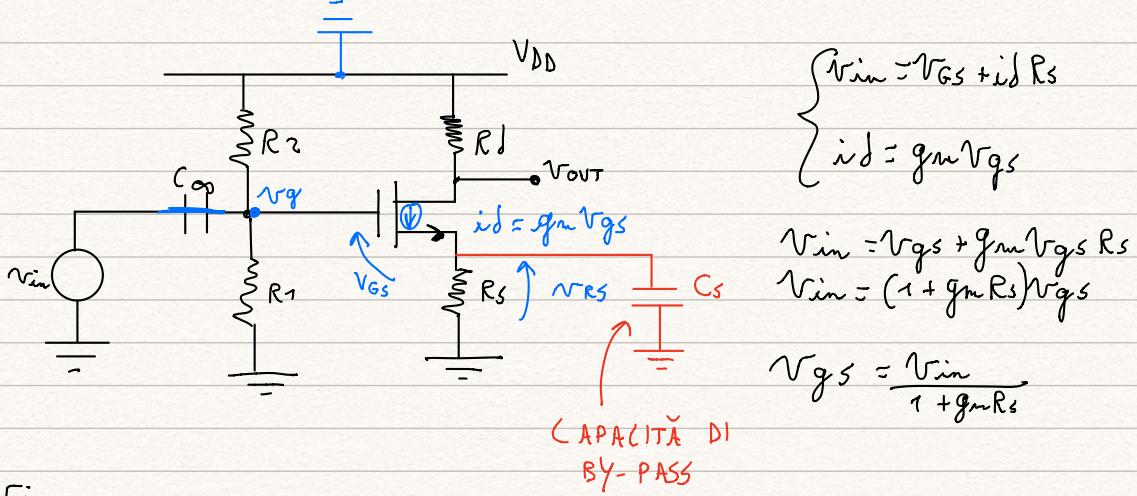
$$\Delta I_D = \Delta K_n [V_{GS} - V_{Tn}]^2 + g_m (-\Delta I_D R_S)$$

$$\Delta I_D (1 + g_m R_S) = \Delta K_n (V_{GS} - V_{Tn})^2 \frac{K_n}{K_n} \frac{1}{I_D} \Delta I_D$$

$$\frac{\Delta I_D}{I_D} = \frac{\Delta K_n}{K_n} \frac{1}{1 + g_m R_S} \quad R_S \gg V_{g_m} \quad 1 + g_m R_S \gg 1$$



ANALISI SU SEGNALE DELLO STADIO SOURCE DEGENERATO

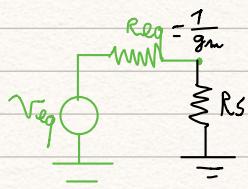
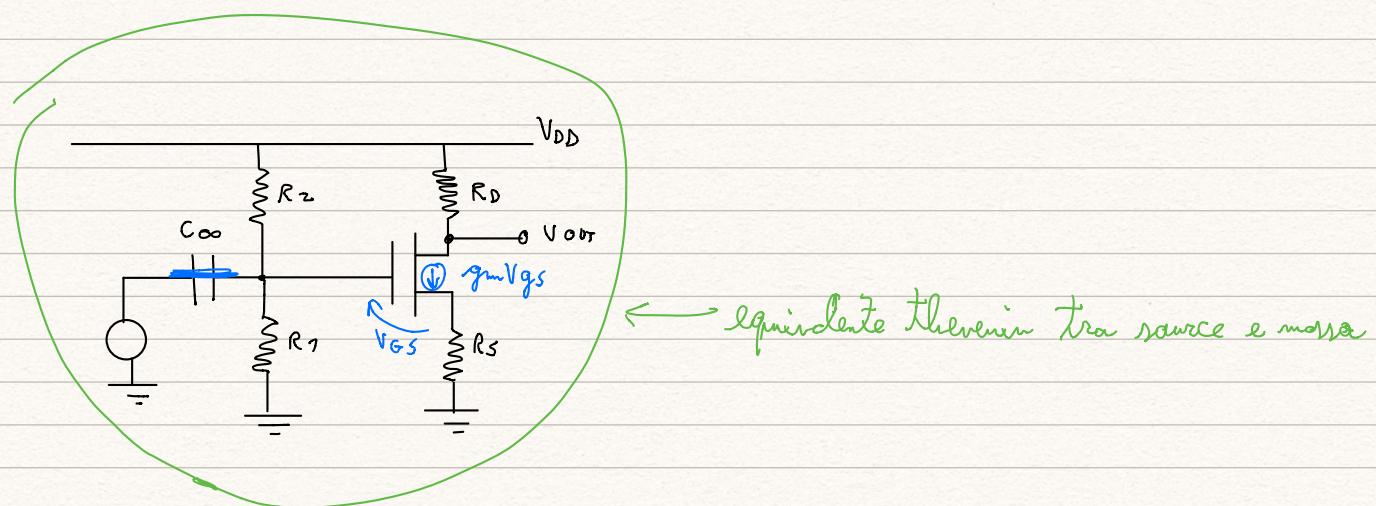


$$id = gm \frac{V_{in}}{1 + gm * R_s}$$

$$V_{out} = -id * R_D = -\frac{gm * R_D}{(1 + gm * R_s)} V_{in}$$

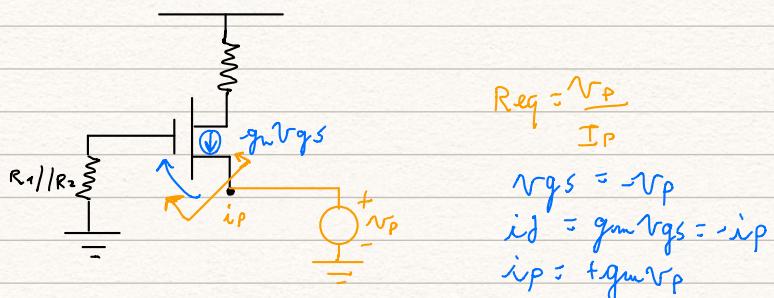
GUADAGNO DI TENSIONE DI UNO STADIO SOURCE DEGENERATO

$$G = \frac{V_{out}}{V_{in}} = -\frac{gm * R_D}{1 + gm * R_s} \approx -\frac{R_D}{R_s}$$



$$i = i_d = \frac{V_{in}}{1/gm + R_s}$$

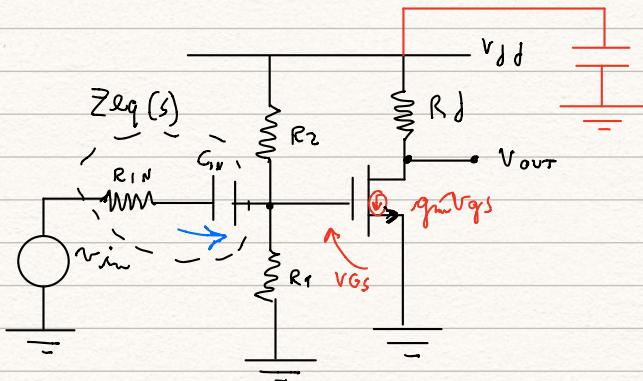
Resistenza vista al source del transistor:



$$Req = \frac{V_p}{I_p}$$

$$\begin{aligned} V_{gs} &= -V_p \\ i_d &= gm * V_{gs} = -ip \\ ip &= +gm * V_p \end{aligned}$$

DIMENSIONAMENTO CAPACITÀ DI DISACCOPPIAMENTO E BYPASS



CAPACITÀ DI DISACCOPPIAMENTO IN INGRESSO

STADIO POLARIZZATO

$$C_{in} \rightarrow Z(s) = \frac{1}{sC_{in}}$$

FUNZIONE DI TRASFERIMENTO (dominio di Laplace)

$$T(s) = \frac{V_{out}(s)}{V_{in}(s)} = -\frac{sC_{in}R_1/R_2}{1+sC_{in}(R_{in}+R_1/R_2)}$$

polo $\frac{1+sC}{s}$

$$Z = C_{in} [R_{in} + R_1//R_2]$$

$$V_{gs}(s) = \frac{R_2/R_1}{Z_{eq}(s) + R_1/R_2} V_{in}(s) = V_{gs}(s)$$

$$V_{out}(s) = -g_m V_{gs}(s) R_d = -g_m R_d \cdot \frac{R_2/R_1}{Z_{eq}(s) + R_1/R_2} \cdot V_{in}(s) = -g_m R_d \frac{R_1/R_2}{1+sC_{in}R_{in} + R_1/R_2} V_{in}(s) =$$

$$= -g_m R_d \frac{sC_{in} R_1/R_2}{1+sC_{in}(R_{in}+R_1/R_2)} V_{in}(s)$$

ZERO DI UNA FUNZIONE DI TRASFERIMENTO

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

POLO DI UNA FUNZIONE DI TRASFERIMENTO

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

$$s = j\omega$$

$$T(j\omega) = -g_m R_d \frac{j\omega C_{in} R_1/R_2}{1+j\omega C_{in}(R_{in}+R_1/R_2)}$$

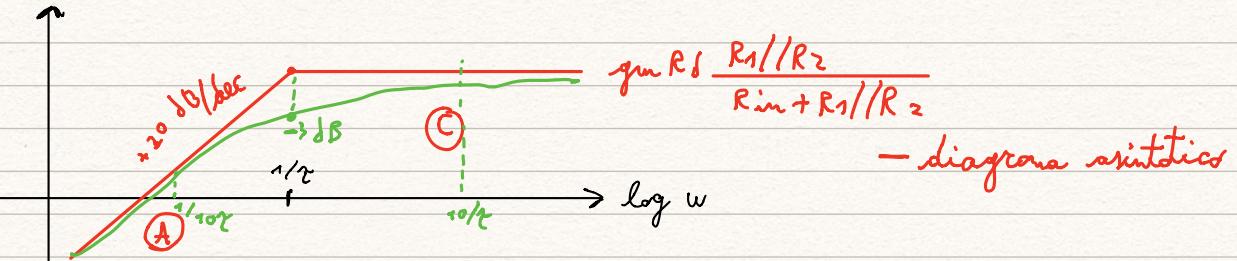
MODULO DELLA FUNZIONE DI TRASFERIMENTO

$$|T(j\omega)| = g_m R_d \frac{\omega C_{in} R_1/R_2}{\sqrt{1+\omega^2 C_{in}^2 (R_{in}+R_1/R_2)^2}}$$

(A)

(B)

(C)



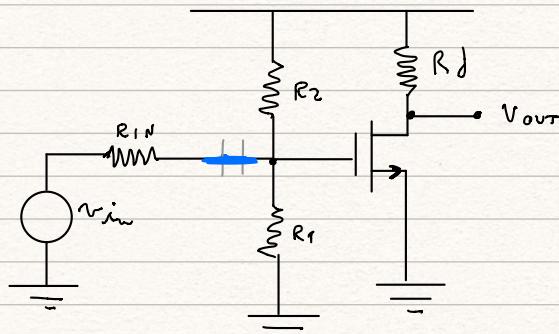
(A) $\omega \ll 1/\gamma$ $1 + \omega^2 \gamma^2 \approx 1$

$$|T(j\omega)| \approx g_m R_d \quad \text{con } C_{in} R_1/R_2$$

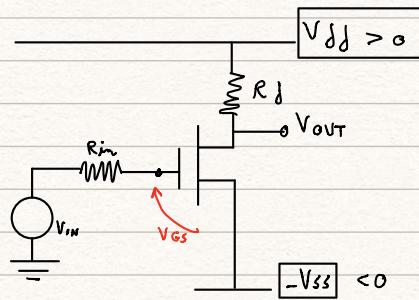
(B) $\omega = 1/\gamma$ $|T(j\omega)| = g_m R_d \cdot \frac{\frac{1}{C_{in} \cdot (R_{in} + R_1/R_2)}}{\sqrt{2}} \cdot C_{in} R_1/R_2 =$

$$= g_m R_d \cdot \frac{R_1/R_2}{R_{in} + R_1/R_2} \cdot \frac{1}{\sqrt{2}}$$

(C) $\omega \gg 1/\gamma$ $|T(j\omega)| = g_m R_d \cdot \frac{\frac{\omega C_{in} R_1/R_2}{\omega C_{in} (R_{in} + R_1/R_2)}}{\omega C_{in} (R_{in} + R_1/R_2)}$



ACCOPPIAMENTO IN CONTINUA;



ALIMENTAZIONE DUALE

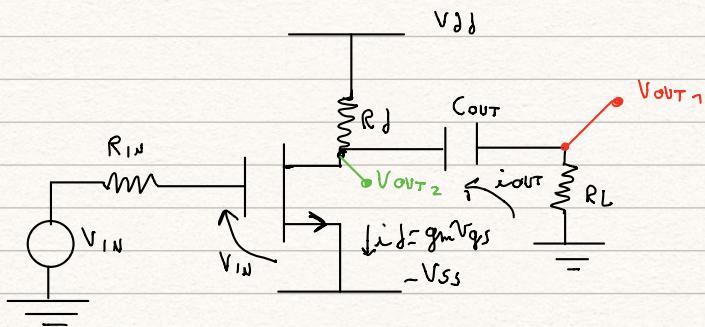
$$T(s) = -g_m R_d$$

- amplifica anche DC
- resistenza ingresso R_{in}^* $\rightarrow \infty$
- due alimentazioni: una positiva e una negativa

POLARIZZAZIONE

$$V_{GS} = V_G - V_S = 0 - (-V_{SS}) = V_{SS} > 0 \quad (> V_{TN})$$

DIMENSIONAMENTO DELLA CAPACITÀ DI DISACCOPPIAMENTO DI USCITA



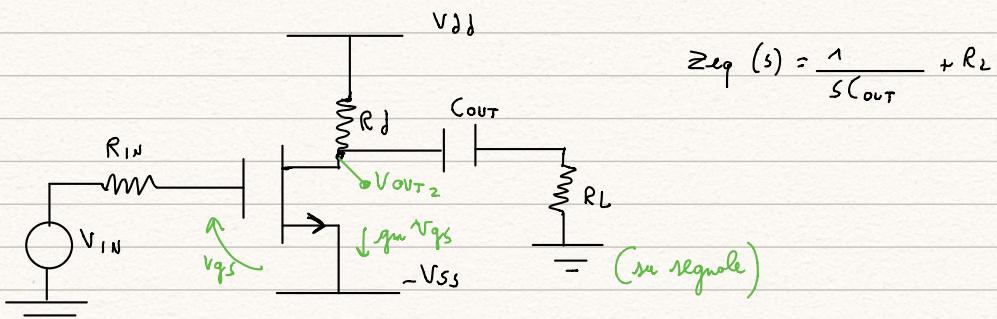
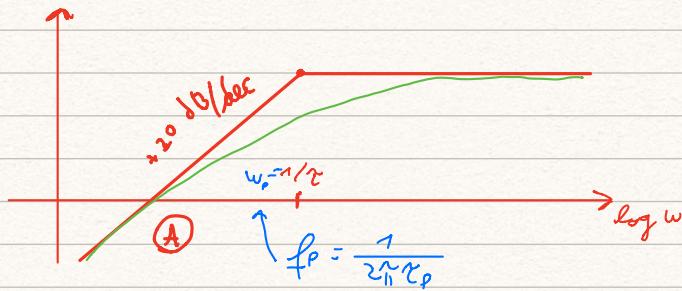
$$T(s) \stackrel{\Delta}{=} \frac{V_{OUT_1}(s)}{V_{IN}(s)} = -\frac{g_m s C_{OUT} R_d R_L}{1 + s C_{OUT} (R_d + R_L)}$$

$$i_{OUT} = g_m V_{QS} \cdot \frac{R_d}{R_d + 1/s C_{OUT} + R_L}$$

$\underbrace{\qquad\qquad\qquad}_{Z_{eq}}$

$$V_{OUT_1} = -i_{OUT} R_L = -g_m V_{QS} \frac{R_d R_L s C_{OUT}}{1 + s C_{OUT} (R_d + R_L)}$$

- ZERO nell'origine
- POLO $\tau_p = C_{OUT} (R_d + R_L)$
- $|T(j\omega)|_{HF} = g_m \cdot \frac{R_d R_L}{R_d R_L} = g_m (R_d / R_L)$

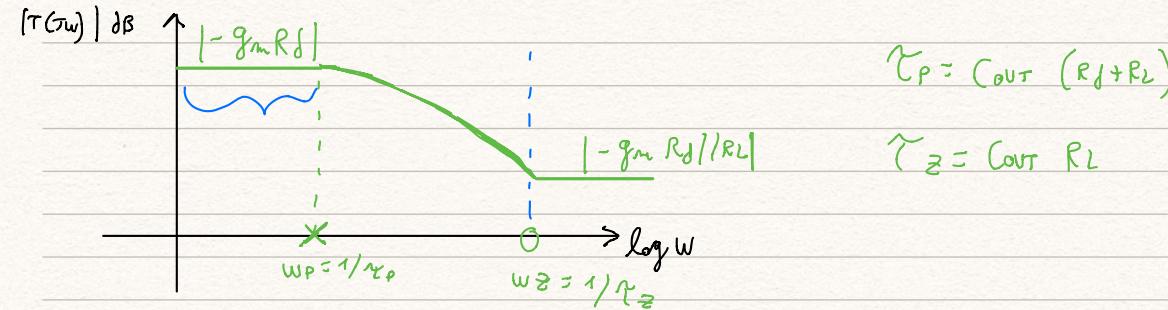


$$Z_{eq}(s) = \frac{1}{s C_{OUT}} + R_L$$

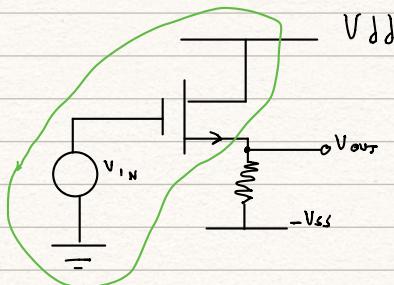
$$V_{OUT_2}(s) = -g_m V_{IN}(s) \quad R_d // Z_{eq}(s) = -g_m V_{IN}(s) = -g_m V_{IN}(s) \quad \frac{R_d (1 + s C_{OUT} R_L)}{1 + s C_{OUT} (R_d + R_L)}$$

$$\frac{R_d (1/s C_{OUT} + R_L)}{R_d + 1/s C_{OUT} + R_L} = \frac{R_d (1 + s C_{OUT} R_L)}{1 + s C_{OUT} (R_d + R_L)}$$

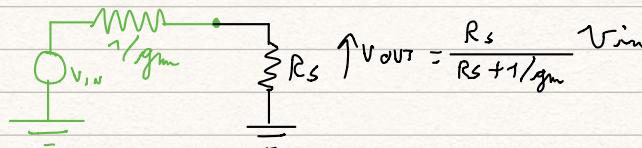
ZERO
 $s_2 = -\frac{1}{C_{OUT} R_L}$
 $\approx z = C_{OUT} R_L$
 POLO, UGUALE
 A PRIMA!



SOURCE FOLLOWER:



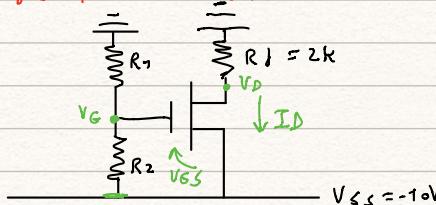
EQ. THEVENIN



$$G \stackrel{\Delta}{=} \frac{V_{out}}{V_{in}} = \frac{R_s}{R_s + 1/gm} = \frac{g_m R_s}{1 + g_m R_s} < 1$$

- STADIO NON INVERTENTE
 - BUFFER DI TENSIONE
- resistenza in ingresso $\rightarrow \infty$
 - resistenza di uscita bassa
 - guadagno circa unitario

esercizio di POLARIZZAZIONE



$$K_n = 1/2 \mu m C_{ox} \frac{W}{L} = 1mA/V^2$$

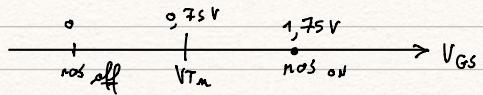
$$V_{Tn} = g_m V$$

$$R_1 = 825 k$$

$$R_2 = 175 k$$

$$\begin{aligned}
 I_G = 0 \longrightarrow V_G = V_{ss} + \frac{R_2}{R_1 + R_2} (-10V) = -10V \left[\frac{(R_1 + R_2)}{R_1 + R_2} + \frac{R_2}{R_1 + R_2} \right] = -10V \frac{R_1}{R_1 + R_2} = \\
 \approx -8.25V
 \end{aligned}$$

$$V_{GS} = V_G - V_S = -8.25V - (-10V) = +1.75V > V_{Tn}$$



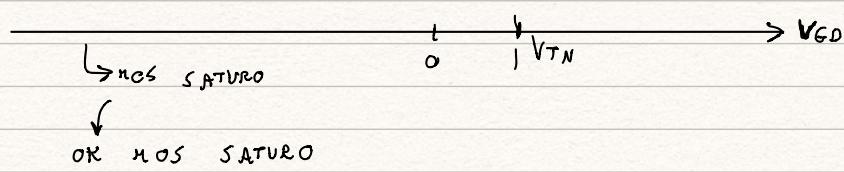
HP SATURAZIONE N MOS

$$I_D = K_n (V_{GS} - V_{Tn})^2 = 1 \text{ mA/V}^2 \quad (1.75V - 0.75V)^2 = 1 \text{ mA}$$

$$V_D = -I_D R_D = -1 \text{ mA} \cdot 2 \text{ k}\Omega = -2 \text{ V}$$

$$V_{GD} = -8.25 \text{ V} - (-2 \text{ V}) = -6.25 \text{ V}$$

, c'è canale lots drain
non c'è canale al drain , MOS shielded



ds. per cosa

