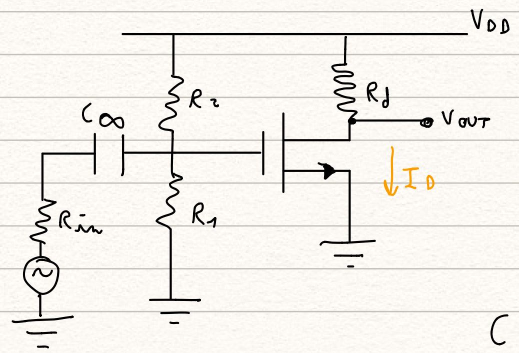
STADIO SOURCE A MASSA:



V_{DD} generatore di tensione DC

v_{in} generatore di segnale

$$C_\infty \begin{cases} |z| = \frac{1}{\omega C_\infty} = \infty & \omega = 0 \text{ in DC} \\ |z| = \frac{1}{\omega C_\infty} = 0 & \forall \omega \neq 0 \end{cases}$$

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

1: Capacità circuiti aperti perché in DC

2: generatori di segnali spenti

3: |Hp| mos aperti in saturazione

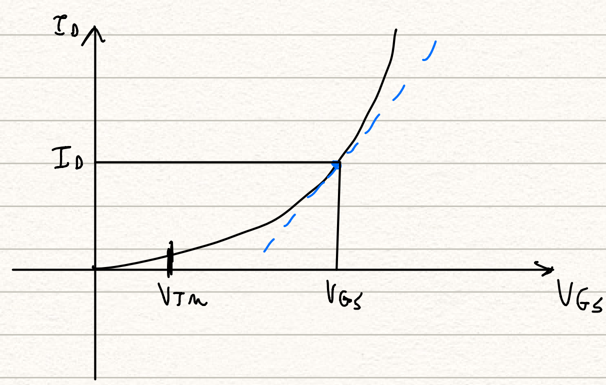
da verificare

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

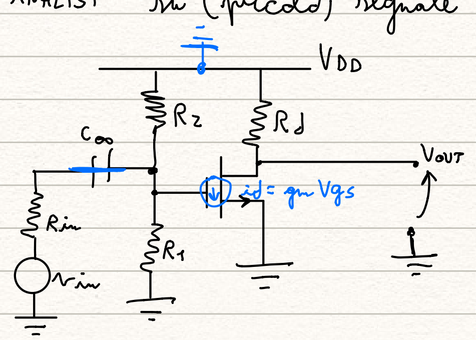
$$V_D = V_{OUT} = V_{DD} - I_D R_d \quad : \quad I_{div} = \frac{V_{DD}}{R_1 + R_2}$$

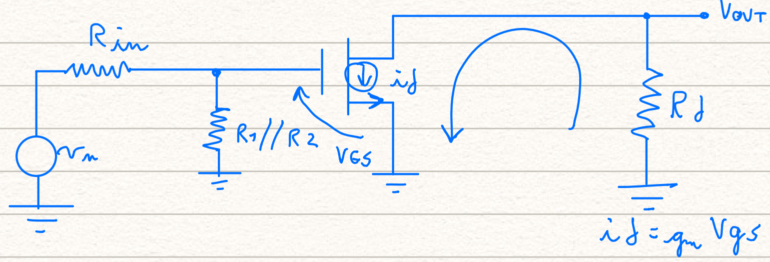
$V_{GD} = V_G - V_D$ se $V_{GD} < V_{Tn} \longrightarrow$ OK mos saturo

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



Ⓑ ANALISI su (piccolo) segnale





$V_{gs} \ll 2(V_{GS} - V_{Tn})$

$$v_{gs} = \frac{R_1 // R_2}{R_{in} + R_1 // R_2} \longrightarrow i_d = g_m V_{gs}$$

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

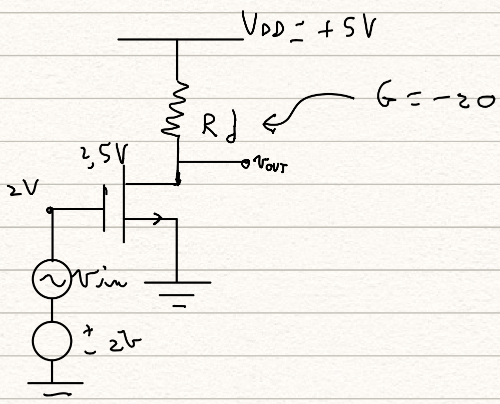
$$G \triangleq \frac{v_{OUT}}{v_{in}} = -g_m R_d \underbrace{\frac{R_1 // R_2}{R_{in} + R_1 // R_2}}_{\text{partizione in ingresso}}$$

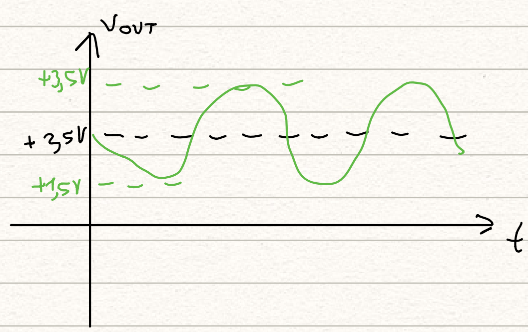
- Stadio invertente

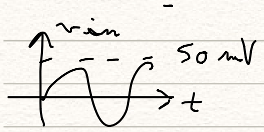
ERRORE DI LINEARITÀ:

$$\varepsilon = \frac{v_{gs}}{2(V_{GS} - V_{Tn})}$$

esempio:

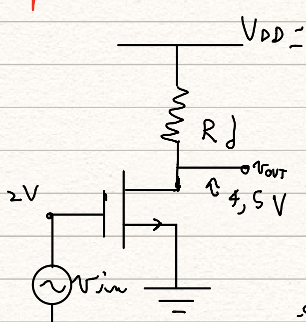




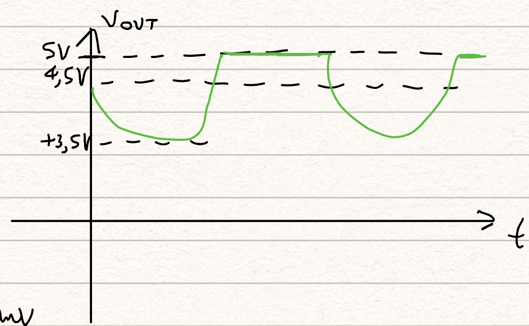


$$V_{OUT} = |G V_{in}| = |-20 \cdot 50\,mV| = |-1V| = 1V$$

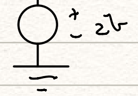
esempio 2:



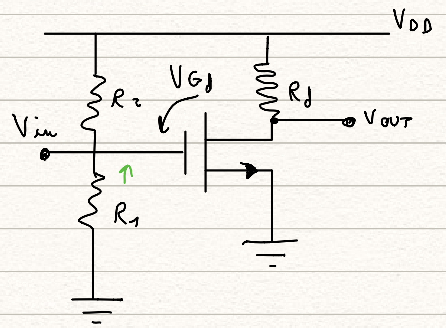
$G = -20$



ampiezza $V_{in} = 50\,mV$



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



V_{OUT} può salire fino a V_{DD}

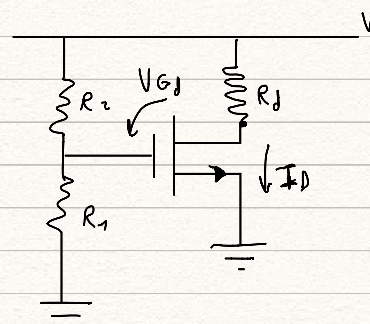
$V_{OUT} < V_{DD}$

$\Delta V_{OUT} = V_{DD} - V_{OUT}$ in polarizzazione

$V_{Gd} < V_{Tn}$ per garantire la saturazione del mos

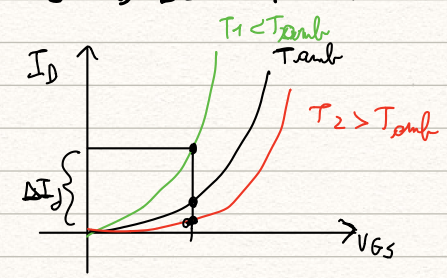
$$V_{Gd} = V_G + v_g - \underbrace{(V_D + v_d)}_{V_d} = V_G + v_g - V_D - v_d < V_{Tn}$$

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



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

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

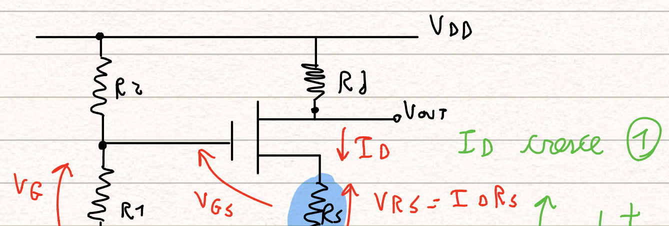


1% / C°

$$\Delta I_D = \Delta K_n \boxed{(V_{GS} - V_{Tn})^2 \cdot K_n} \; I_D$$

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

STADIO DI DEGENERAZIONE DI SOURCE:



↑ caduta su R_S cresce ②

③ V_{GS} diminuisce

$V_G = V_{GS} + I_D R_S$

Ⓐ POLARIZZAZIONE

$I_D = K_n (V_{GS} - V_{Tn})^2$ (sotto le HP che mos saturo)

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

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

$$\begin{cases} I_D = K_n (V_{GS} - V_{Tn})^2 \\ V_G = V_{GS} + I_D R_S \end{cases} \rightarrow \boxed{I_D, V_{GS}} \rightarrow$$ ho solo una soluzione fisicamente possibile

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

$V_{GD} < V_{Tn}$? SI → OK MOS SATURO

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

$V_{GS} = V_G - I_D R_S$

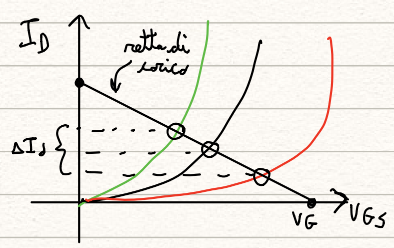
$\Delta I_D = \Delta K_n [V_{GS}(K_n) - V_{Tn}]^2 + K_n \, 2(V_{GS} - V_{Tn}) \Delta V_{GS}$

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

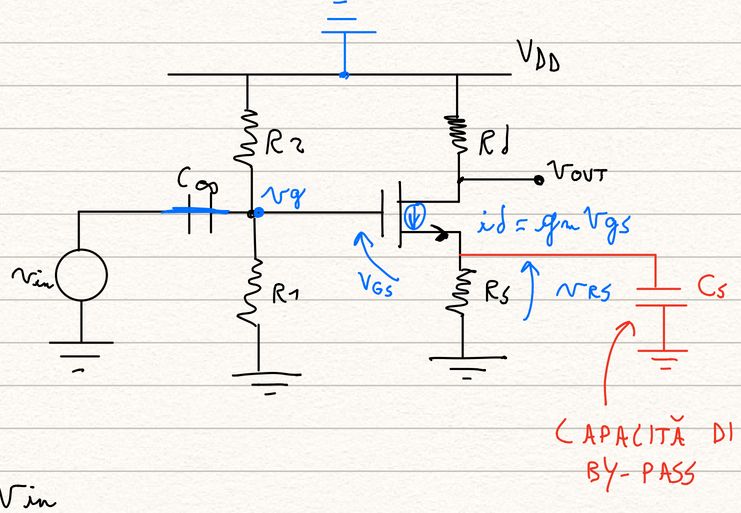
$\Delta I_D = \Delta K_n [V_{GS} - V_{Tn}]^2 + g_m (-\Delta I_D R_S)$

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

$$\boxed{\frac{\Delta I_D}{I_D} = \frac{\Delta K_n}{K_n} \frac{1}{1 + g_m R_S}}$$ ← $R_S >> 1/g_m$ $1 + g_m R_S >> 1$



ANALISI SU SEGNALE DELLO STADIO SOURCE DEGENERATO



$$\begin{cases} v_{in} = v_{GS} + i_d R_S \\ i_d = g_m v_{gs} \end{cases}$$

$$v_{in} = v_{gs} + g_m v_{gs} R_S$$

$$v_{in} = (1 + g_m R_S) v_{gs}$$

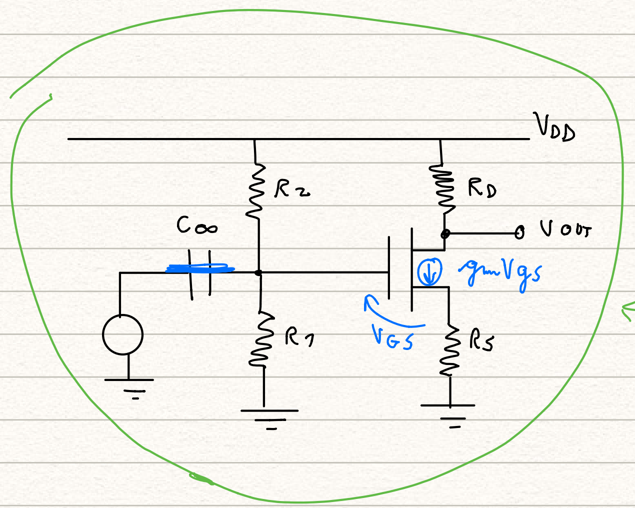
$$v_{gs} = \frac{v_{in}}{1 + g_m R_S}$$

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

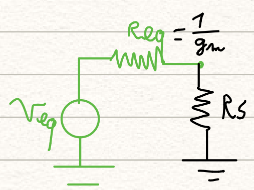
$$V_{OUT} = -i_d R_D = -\frac{g_m R_D}{(1 + g_m R_S)} V_{in}$$

GUADAGNO DI TENSIONE DI UNO STADIO SOURCE DEGENERATO

$$G = \frac{V_{OUT}}{V_{in}} = -\frac{g_m R_D}{1 + g_m R_S} \simeq -\frac{R_D}{R_S}$$

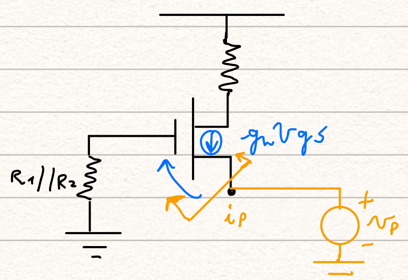


equivalente thevenin tra source e massa



$$\boxed{i = i_d = \frac{v_{in}}{1/g_m + R_S}}$$

Resistenza vista al source del transistor:



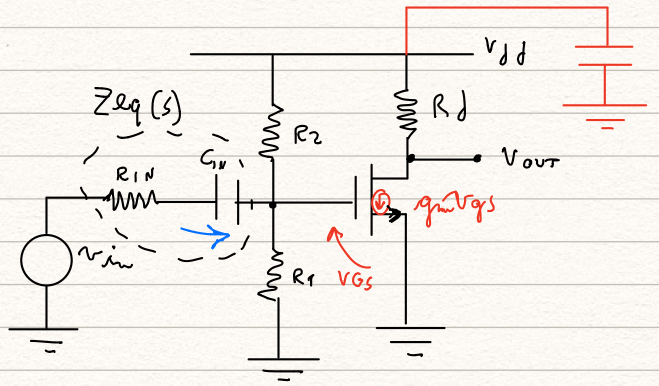
$$R_{eq} = \frac{v_p}{I_p}$$

$$v_{gs} = -v_p$$

$$i_d = g_m v_{gs} = -i_p$$

$$i_p = +g_m v_p$$

DIMENSIONAMENTO CAPACITÀ DI DISACCOPPIAMENTO E BYPASS



CAPACITÀ DI DISACCOPPIAMENTO IN INGRESSO

STADIO POLARIZZATO

$$C_{in} \longrightarrow Z_{C_{in}}(s) = \frac{1}{sC_{in}}$$

FUNZIONE DI TRASFERIMENTO (dominio di Laplace)

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

ZERO

polo $1+s\tau$

$$\tau = C_{in}\left[R_{in}+R_1//R_2\right]$$

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

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

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

ZERO DI UNA FUNZIONE DI TRASFERIMENTO

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

POLO DI UNA FUNZIONE DI TRASFERIMENTO

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

$$\boxed{s = j\omega}$$

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

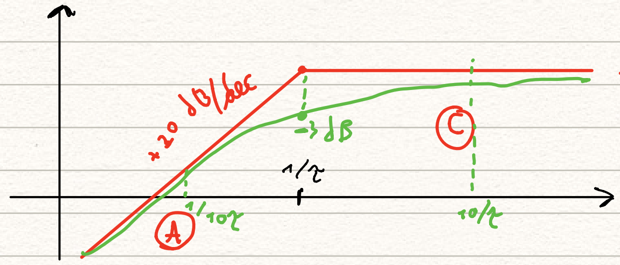
MODULO DELLA FUNZIONE DI TRASFERIMENTO

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

$\omega \ll 1/\tau$ (A)

$\omega = 1/\tau$ (B)

$\omega \gg 1/\tau$ (C)



$g_m R_d \frac{R_1//R_2}{R_{in}+R_1//R_2}$

— diagramma asintotico

(A) $\omega \ll 1/\tau$ $\quad 1+\omega^2\tau^2 \simeq 1$

$$|T(j\omega)| \simeq g_m R_d \; \omega C_{in} \; R_1//R_2$$

(B) $\omega = 1/\tau$

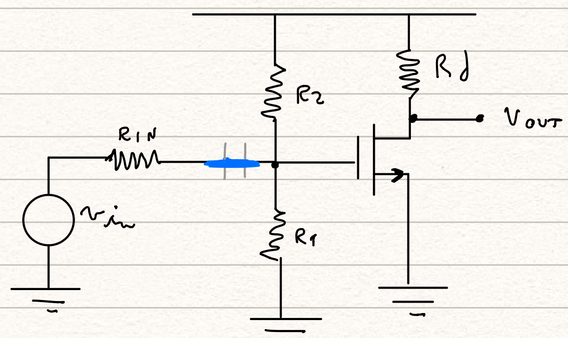
POLO

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

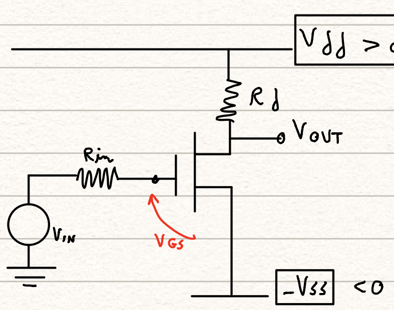
$$= g_m R_d \frac{R_1//R_2}{R_{in}+R_1//R_2} \cdot \frac{1}{\sqrt{2}}$$

(C) $\omega \gg 1/\tau$

$$|T(j\omega)| = g_m R_d \underbrace{\frac{\cancel{\omega}\,\cancel{C_{IN}}\,R_1//R_2}{\cancel{\omega}\,\cancel{C_{IN}}\,(R_{IN}+R_1//R_2)}}$$



ACCOPPIAMENTO IN CONTINUA:



ALIMENTAZIONE DUALE

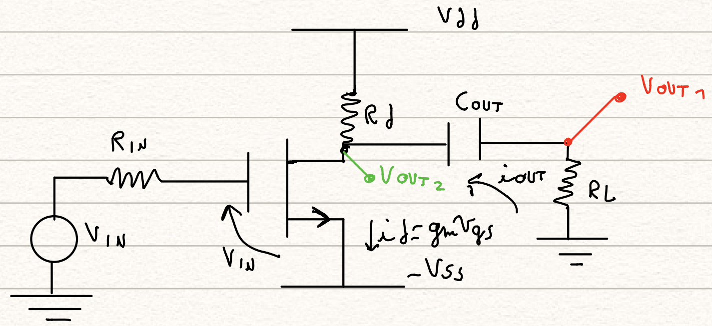
$$T(s) = -g_m R_d$$

- amplifica anche DC
- resistenza ingresso $R^* \to \infty$
- due alimentazioni: una positiva e una negativa

POLARIZZAZIONE

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

DIMENSIONAMENTO DELLA CAPACITÀ DI DISACCOPPIAMENTO DI USCITA

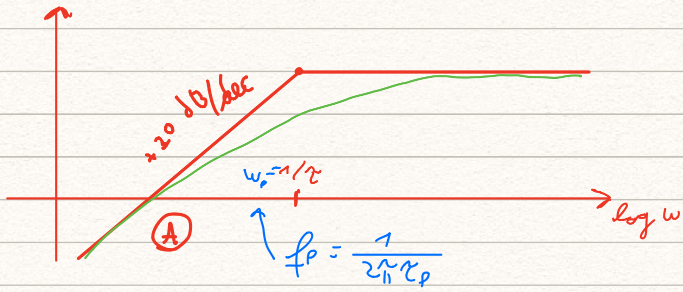


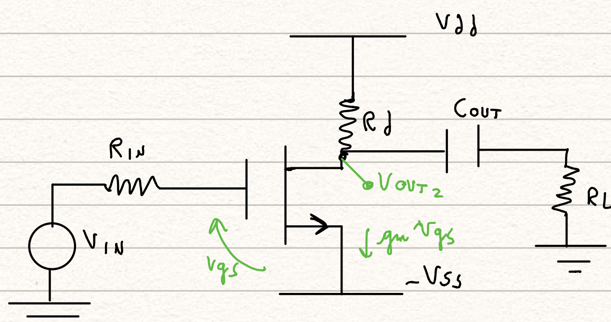
$$T(s) \triangleq \frac{V_{OUT1}(s)}{V_{IN}(s)} = -g_m \frac{sC_{OUT} R_d R_L}{1 + sC_{OUT}(R_d + R_L)}$$

$$i_{OUT} = g_m V_{gs} \cdot \frac{R_d}{R_d + \underbrace{1/sC_{OUT} + R_L}_{Z_{eq}}}$$

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

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





(su regole)

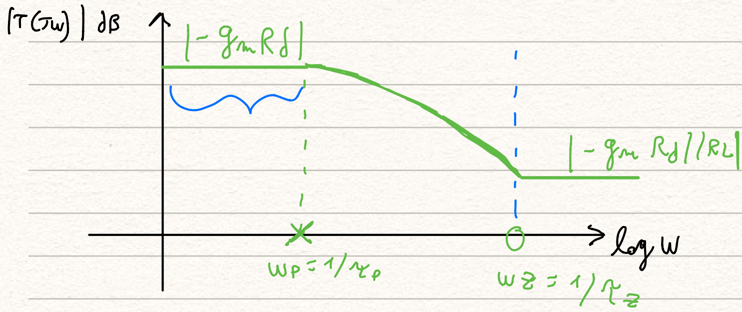
$$Z_{eq}(s) = \frac{1}{sC_{OUT}} + R_L$$

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

ZERO $s_z = -\frac{1}{C_{OUT} R_L}$, $\tau_z = C_{OUT} R_L$

POLO UGUALE A PRIMA!

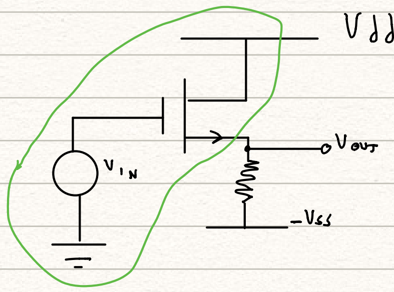
$$\frac{R_d(1/sC_{OUT} + R_L)}{R_d + 1/sC_{OUT} + R_L} = \frac{R_d(1 + sC_{OUT} R_L)}{1 + sC_{OUT}(R_d + R_L)}$$



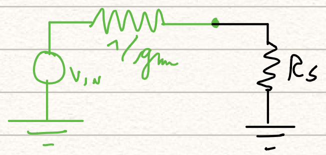
$\tau_p = C_{OUT}\,(R_d + R_L)$

$\tau_z = C_{OUT}\,R_L$

SOURCE FOLLOWER:



EQ. THEVENIN



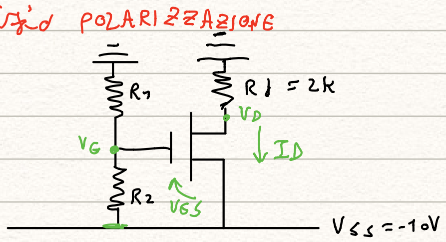
$$V_{OUT} = \frac{R_s}{R_s + 1/g_m} V_{in}$$

$$G \triangleq \frac{V_{OUT}}{V_{IN}} = \frac{R_S}{R_S + 1/g_m} = \frac{g_m R_S}{1 + g_m R_S} < 1$$

- STADIO NON INVERTENTE
- BUFFER DI TENSIONE

- resistenza in ingresso $\to \infty$
- resistenza di uscita bassa
- guadagno circa unitario

esercizio POLARIZZAZIONE



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

$V_{Tn} = 0{,}75\,V$

$R_1 = 825\ K$

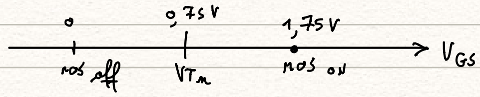
$R_2 = 175\ K$

$$I_G = 0 \longrightarrow V_G = V_{SS} + \frac{R_2}{R_1 + R_2}(-10V) = -10V\left[\frac{(R_1+R_2)}{R_1+R_2} + \frac{R_2}{R_1+R_2}\right] = -10V\,\frac{R_1}{R_1+R_2} =$$

$$= -8{,}25\,V$$

$$V_{GS} = V_G - V_S = -8{,}25V - (-10V) = +1{,}75\,V > V_{Tn}$$

MOS ON

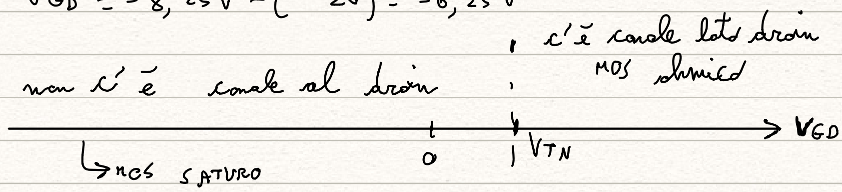


HP SATURAZIONE N MOS

$I_D = K_n (V_{GS} - V_{Tn})^2 = 1\,mA/V^2 \; (1{,}75\,V - 0{,}75\,V)^2 = 1\,mA$

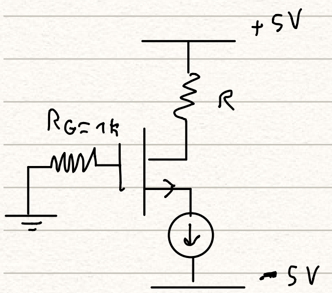
$V_D = -I_D R_d = -1\,mA \cdot 2\,k\Omega = -2\,V$

$V_{GD} = -8{,}25\,V - (-2\,V) = -6{,}25\,V$



OK MOS SATURO

Es. per casa



$V_T = 1{,}5\,V$ determinare il massimo valore possibile per R per mantenere il mos saturo?