

Ricostruzione caratteristica del MOS:

$I_D = Qv$ Corrente nello strato di inversione, funzione di x

$Q(x)$ densità lineare di carica, C_{ox} cap. per unità di superficie del gate

$$\rightarrow Q(x) = WC_{ox} [V_{GS} - V(x) - V_{TH}]$$

$$v = \mu_n E = \mu_n \frac{dV}{dx}$$

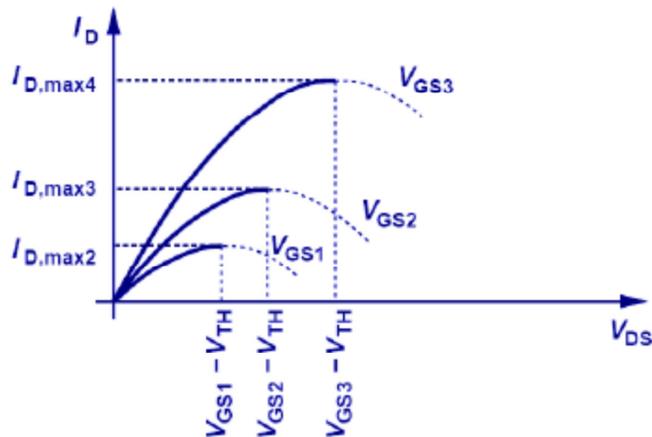
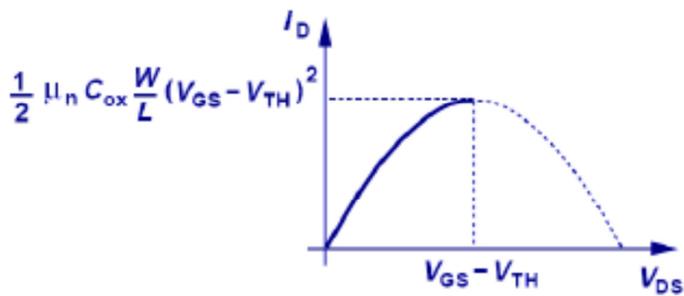
$$\rightarrow I_D = WC_{ox} [V_{GS} - V(x) - V_{TH}] \mu_n \frac{dV}{dx}$$

$$\rightarrow \int_0^L I_D dx = \int_{V_S}^{V_D} WC_{ox} [V_{GS} - V_{TH}] \mu_n dV - \int_{V_S}^{V_D} WC_{ox} V(x) \mu_n dV$$

$$\rightarrow I_D L = WC_{ox} \mu_n [V_{GS} - V_{TH}] V_{DS} - \frac{1}{2} WC_{ox} \mu_n V_{DS}^2$$

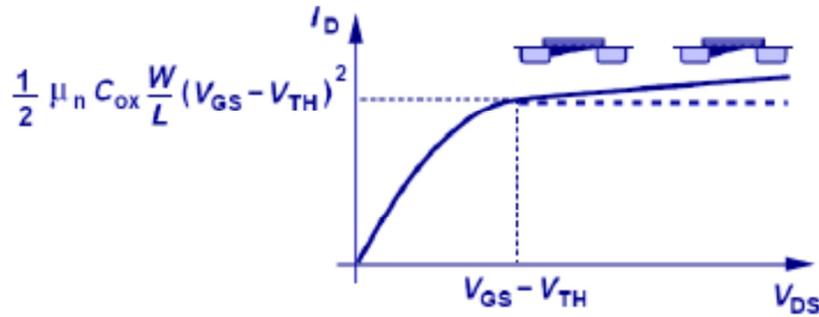
$$\rightarrow I_D = \frac{1}{2} \frac{W}{L} C_{ox} \mu_n [2(V_{GS} - V_{TH}) V_{DS} - V_{DS}^2]$$

$$\rightarrow I_D^{\max} = \frac{1}{2} \frac{W}{L} C_{ox} \mu_n [(V_{GS} - V_{TH})^2]$$

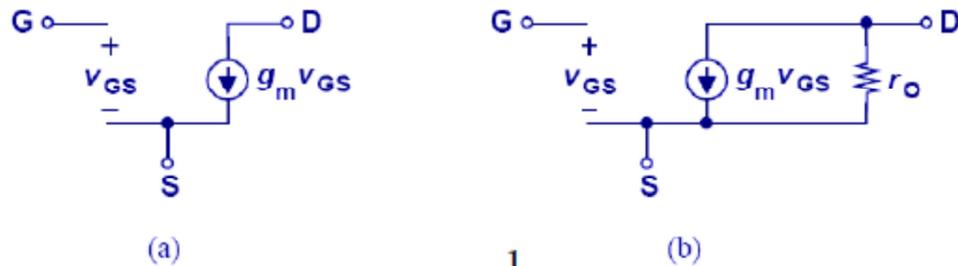


Correzione dovuta alla dipendenza di L da V_{DS} :

$$I_D = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_{TH})^2 (1 + \lambda V_{DS})$$



Modello del MOS per piccoli segnali:



$$r_o \approx \frac{1}{\lambda I_D}$$

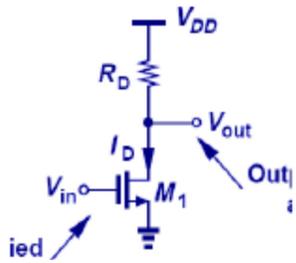
$$I_D = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_{TH})^2 [1 + \lambda (V_{DS} - V_{D,sat})]$$

$$i_d = \frac{\partial I_D}{\partial V_{GS}} v_{gs} + \frac{\partial I_D}{\partial V_{BS}} v_{bs} + \frac{\partial I_D}{\partial V_{DS}} v_{ds} \equiv g_m v_{gs} + g_{mb} v_{bs} + \frac{1}{r_o} v_{ds}$$

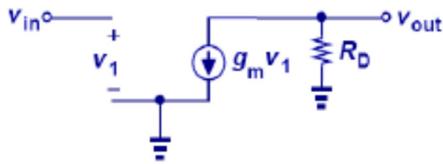
Transconduttanza del MOS (espressioni equivalenti):

$$g_m = \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_{TH}) \quad g_m = \sqrt{2 \mu_n C_{ox} \frac{W}{L} I_D} \quad g_m = \frac{2 I_D}{V_{GS} - V_{TH}}$$

Amplificatore Common Source (CS):



Modello per piccoli segnali:



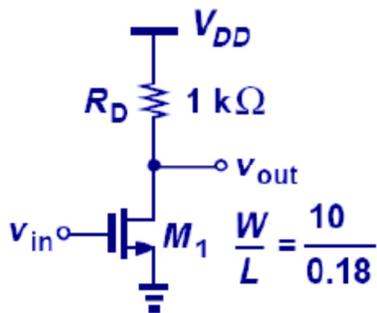
Guadagno di tensione:

$$\lambda = 0$$

$$A_v = -g_m R_D$$

$$A_v = -\sqrt{2\mu_n C_{ox} \frac{W}{L}} I_D R_D$$

Condizione di saturazione (richiesta per amp. lineare):



$$V_{out} > V_{in} - V_{TH}$$

$$\Rightarrow V_{DD} - R_D I_D > (V_{GS} - V_{TH})$$

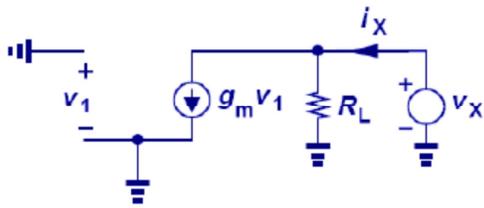
Es:

$$\left. \begin{array}{l} V_{DD} = +10V \\ V_{TH} = 1.5V \\ I_D = 5 \text{ mA} \end{array} \right\} \rightarrow 10 - 10^3 I_D > V_{in} - 1.5$$

$$\rightarrow V_{in} < 10 + 1.5 - 10^3 I_D = 11.5 - 10^3 I_D$$

$$\rightarrow V_{in} < 11.5 - 5 \text{ V} = 6.5 \text{ V}$$

CS con carico resistivo:

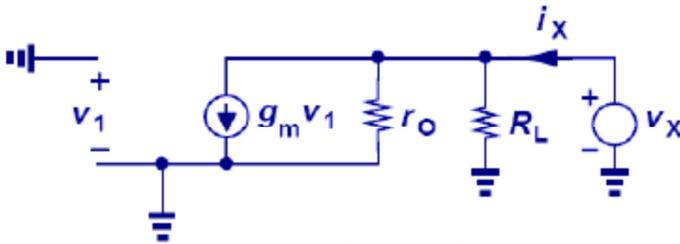


$$A_v = -g_m R_L$$

$$R_{in} = \infty$$

$$R_{out} = R_L$$

Tenendo conto della variazione della lunghezza del canale con V_{DS} :



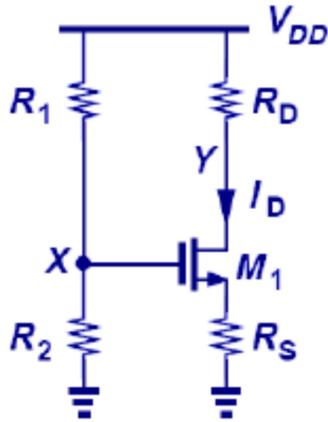
$$A_v = -g_m (R_L \parallel r_o)$$

$$R_{in} = \infty$$

$$R_{out} = R_L \parallel r_o$$

Polarizzazione (= bias) del MOS:

1) Schema semplice

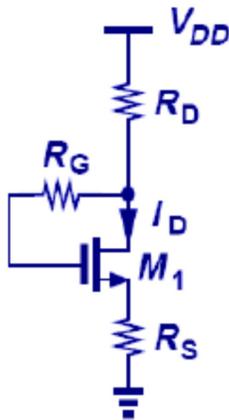


$$\frac{R_1}{R_1 + R_2} V_{DD} = V_{GS} + I_D R_S$$
$$I_D = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_{TH})^2$$

→

$$V_{GS} = -(V_1 - V_{TH}) + \sqrt{V_1^2 + 2V_1 \left(\frac{R_2 V_{DD}}{R_1 + R_2} - V_{TH} \right)}$$
$$V_1 = \frac{1}{\mu_n C_{ox} \frac{W}{L} R_S}$$

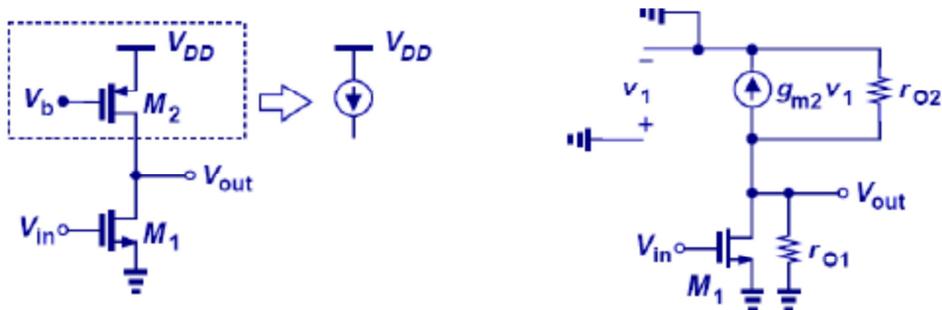
2) Schema a self-bias



$$I_D R_D + V_{GS} + R_S I_D = V_{DD}$$

$$I_D = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_{TH})^2$$

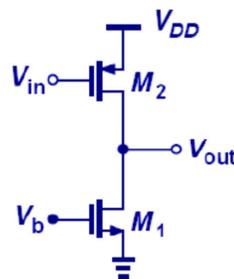
3) Schemi con generatore di corrente



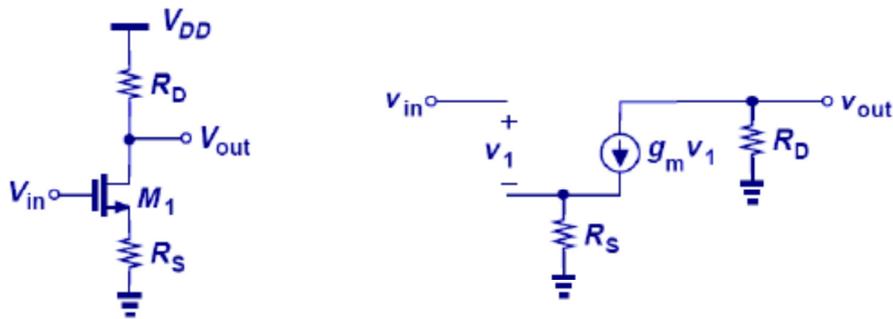
Considerevole simmetria NMOS ↔ PMOS: Stesso guadagno

$$A_v = -g_{m1} (r_{o1} \parallel r_{o2})$$

$$R_{out} = r_{o1} \parallel r_{o2}$$

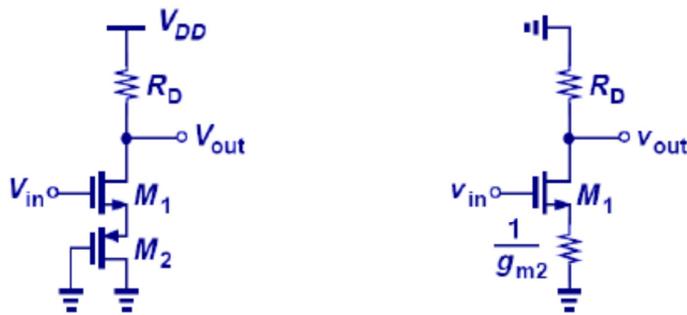


CS con resistenza sul source (assumendo r_0):



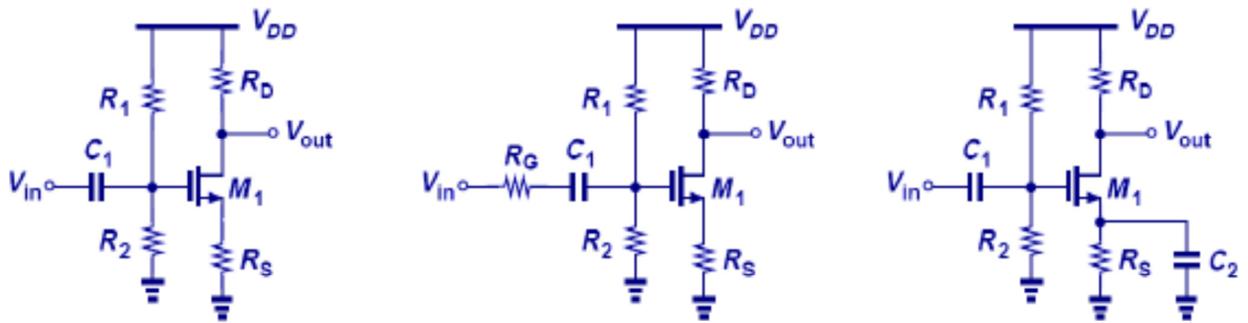
$$A_v = -\frac{R_D}{\frac{1}{g_m} + R_S}$$

PMOS in saturazione invece di una resistenza:



$$A_v = -\frac{R_D}{\frac{1}{g_{m1}} + \frac{1}{g_{m2}}}$$

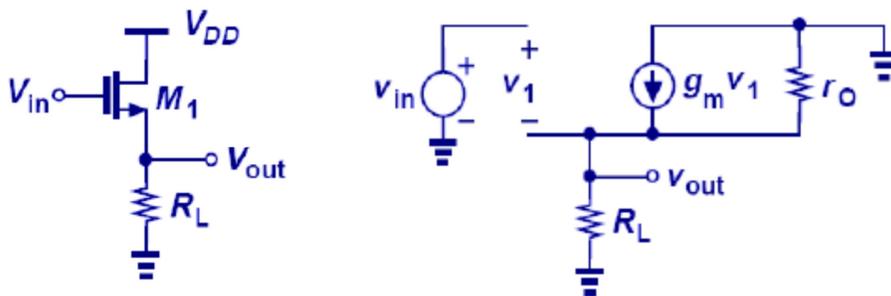
Schema completo:



$$A_v = \frac{R_1 \parallel R_2}{R_G + R_1 \parallel R_2} \cdot \frac{-R_D}{\frac{1}{g_m} + R_S}$$

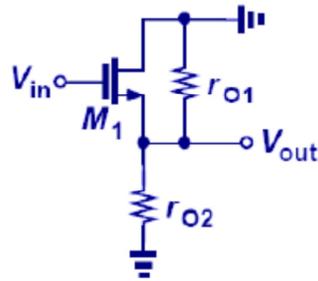
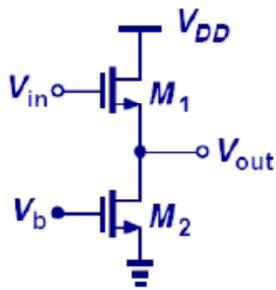
$$A_v = -g_m R_D$$

Source follower:



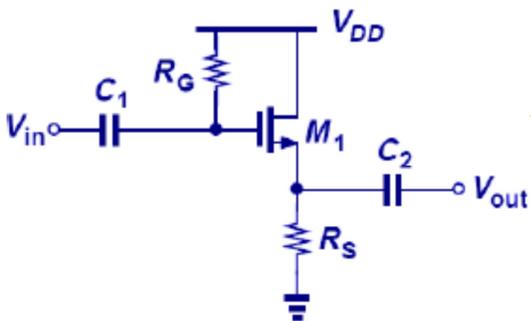
$$\frac{v_{out}}{v_{in}} = \frac{r_O \parallel R_L}{\frac{1}{g_m} + r_O \parallel R_L}$$

Con carico attivo:



$$A_v = \frac{r_{O1} \parallel r_{O2}}{\frac{1}{g_{m1}} + r_{O1} \parallel r_{O2}}$$

Con polarizzazione:



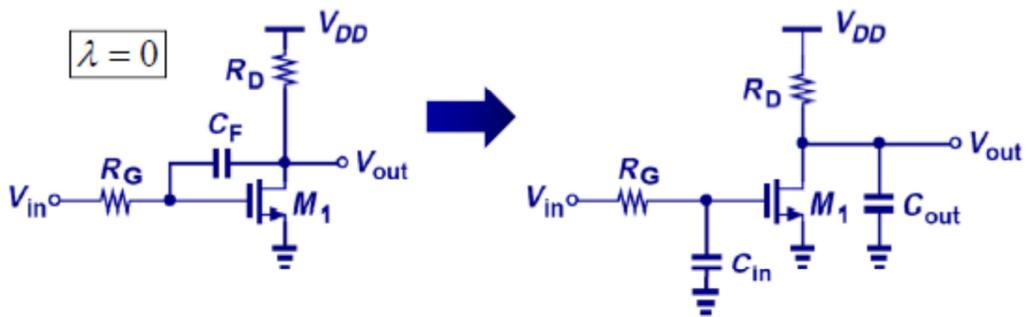
$$I_D = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{DD} - I_D R_S - V_{TH})^2$$

Comportamento del MOS ad alta frequenza:

Effetto delle capacita' intrinseche

Problema simile a quello del BJT: Effetto Miller

→ Teorema di Miller per decomposizione C_F



$$\omega_{in} = \frac{1}{R_G (1 + g_m R_D) C_F}$$

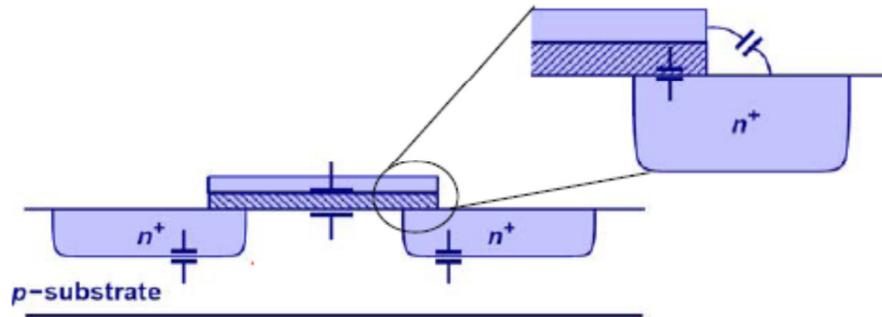
$$\omega_{out} = \frac{1}{R_D \left(1 + \frac{1}{g_m R_D} \right) C_F}$$

Capacita' intrinseche del MOS:

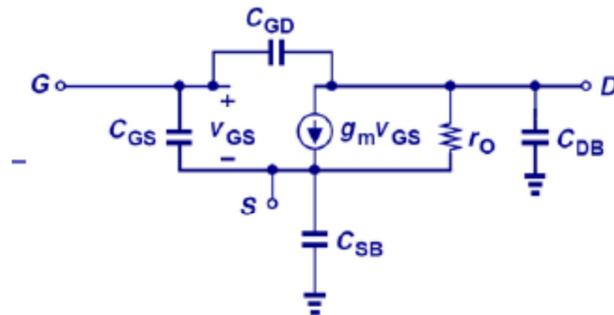
Gate-Canale

Gate-Source e Gate-Drain (Cap. di overlap e da fringing field)

Source-Body e Drain-Body (Cap. di giunzione)



Modello del MOS con capacita':



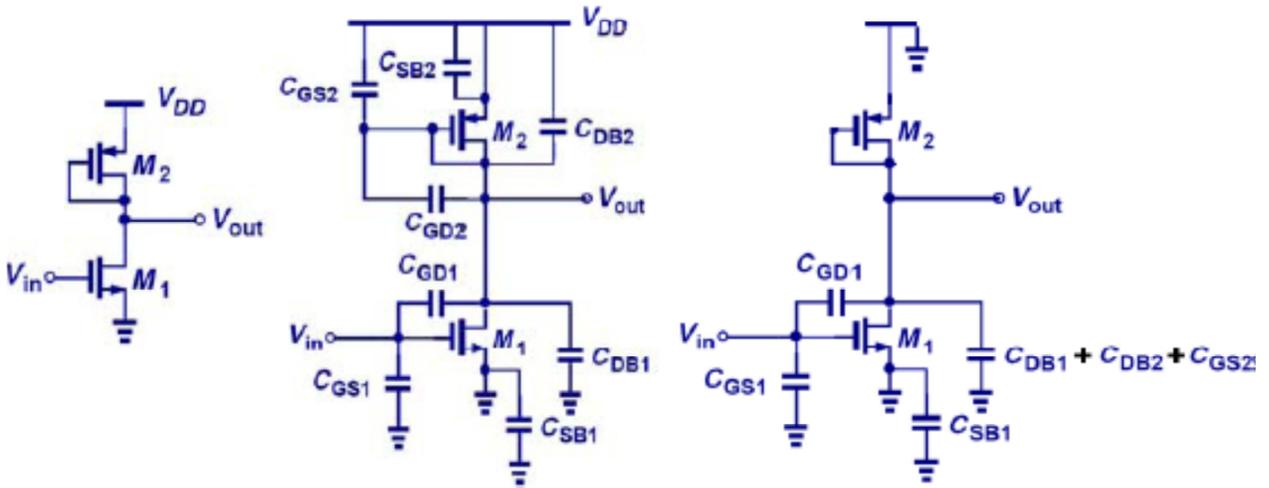
Stadio CS

Capacita' intrinseche

Semplificato

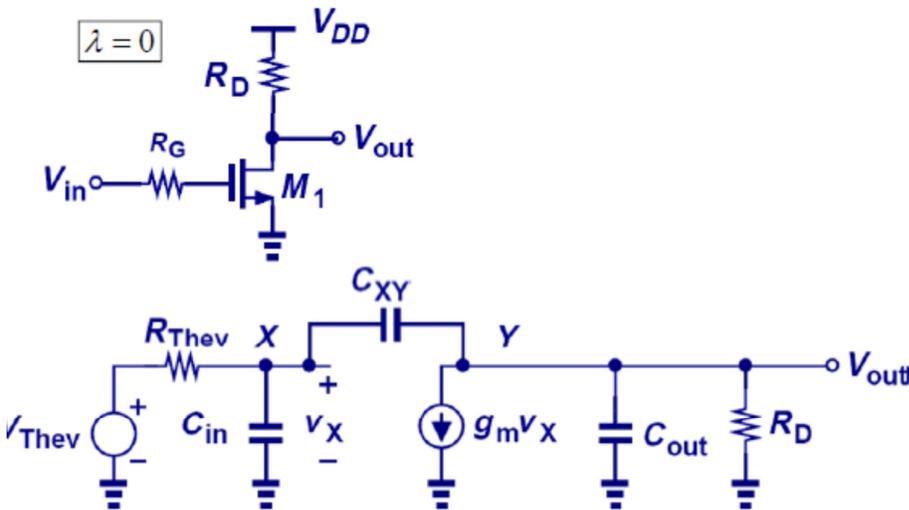
con carico attivo

PMOS

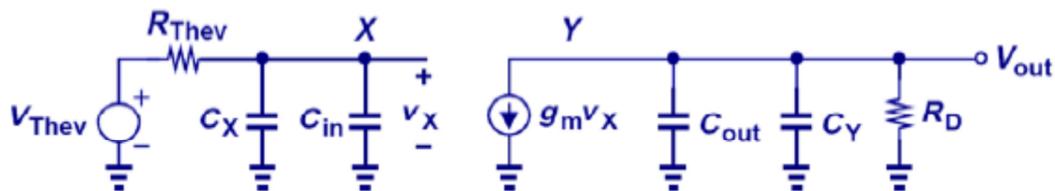


Frequenza di transito: Guadagno di corrente = 1

$$\rightarrow \omega_T = \frac{g_m}{C_{GS}}$$



Con teorema di Miller:



$$V_{\text{Thev}} = V_{\text{in}}$$

$$R_{\text{Thev}} = R_G$$

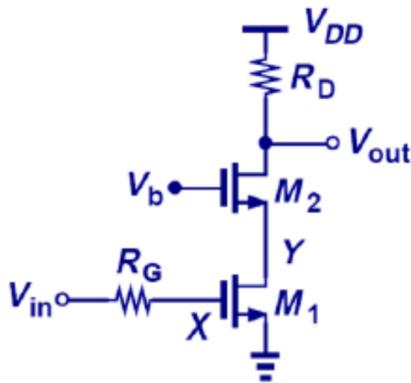
$$C_X = C_{GD} (1 + g_m R_D)$$

$$C_Y = C_{GD} \left(1 + \frac{1}{g_m R_D}\right)$$

$$\omega_{p,in} = \frac{1}{R_{\text{Thev}} (C_{in} + (1 + g_m R_D) C_{GD})}$$

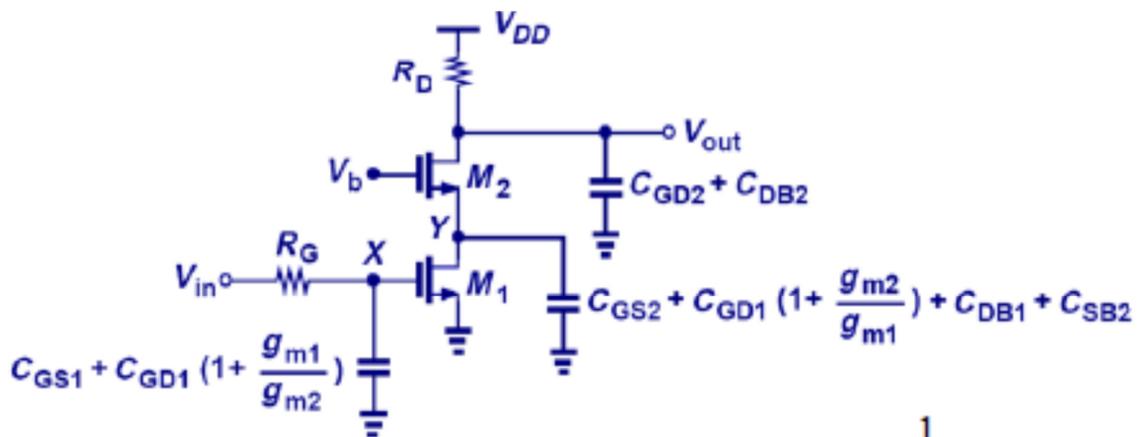
$$\omega_{p,out} = \frac{1}{R_D \left(C_{out} + \left(1 + \frac{1}{g_m R_D}\right) C_{GD} \right)}$$

Cascode con MOS:



$$A_{v,XY} \equiv \frac{v_X}{v_Y} = -g_{m1} \left(\frac{1}{g_{m2}} \right) \approx -1$$

$$\Rightarrow C_X \approx 2C_{XY}$$



1

Poli (← Funzione di trasferimento = Guadagno di tensione):

$$\omega_{p,X} = \frac{1}{R_G \left[C_{GS1} + \left(1 + \frac{g_{m1}}{g_{m2}} \right) C_{GD1} \right]}$$

$$\omega_{p,Y} = \frac{1}{\frac{1}{g_{m2}} \left[C_{DB1} + C_{GS2} + \left(1 + \frac{g_{m2}}{g_{m1}} \right) C_{GD1} + C_{SB2} \right]}$$

$$\omega_{p,out} = \frac{1}{R_D (C_{DB2} + C_{GD2})}$$