Tehnici de proiectare a structurilor VLSI

Structura cursului

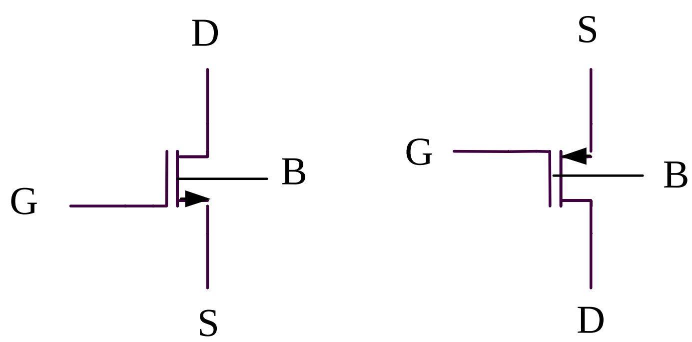
1. Modelarea dispozitivelor MOS active
2. Surse de curent
3. Referinte de tensiune
4. Amplificatoare diferentiale
5. Circuite de multiplicare
6. Amplificatoare operationale. Structuri interne
7. Circuite de ridicare la patrat
8. Rezistente active
9. Structuri pentru realizarea functiilor neliniare complexe
10. Structuri multifunctionale de calcul analogic

Capitolul 1. Modelarea dispozitivelor MOS active

1. Modelul de semnal mare

1. Modelul de semnal mare

NMOS **PMOS**



Notatii:
G = poarta
D = drena
S = sursa
B = substrat

W/L = factor de aspect
K’ = parametru transconductanta
V_T = tensiune de prag
V_{GS} = tensiune substrat-sursa
V_{DS} = tensiune drena-sursa

I. Inversie puternica

$$V_{GS} > V_T$$

a. Saturatie

$$V_{DS} \geq V_{DSsat} = V_{GS} - V_T$$

$$I_D = \frac{K}{2}\left(V_{GS} - V_T\right)^2 \qquad K = K'\frac{W}{L} = \mu_n C_{ox}\frac{W}{L}$$

b. Regiunea liniara

$$V_{DS} < V_{DSsat}$$

$$I_D = K\left[\left(V_{GS} - V_T\right) - \frac{V_{DS}}{2}\right]V_{DS}$$

II. Inversie slaba

$$V_{GS} < V_T$$

$$I_D = I_{D0}\frac{W}{L}\exp\left(\frac{V_{GS} - V_T}{nV_{th}}\right)$$

$$I_D\big|_{sat} = I_D\big|_{i.s.}$$

$$\left.\frac{\partial I_D}{\partial V_{GS}}\right|_{sat} = \left.\frac{\partial I_D}{\partial V_{GS}}\right|_{w.i.}$$

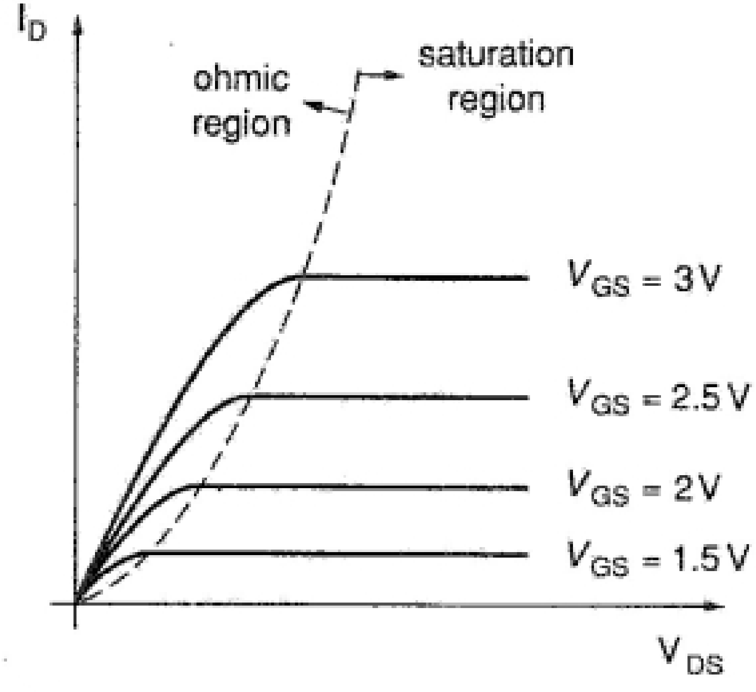
$$\frac{K}{2}\left(V_{GS} - V_T\right)^2 = I_{D0}\frac{W}{L}\exp\left(\frac{V_{GS} - V_T}{nV_{th}}\right)$$

$$K\left(V_{GS} - V_T\right) = I_{D0}\frac{W}{L}\frac{1}{nV_{th}}\exp\left(\frac{V_{GS} - V_T}{nV_{th}}\right)$$

$$\Rightarrow \begin{cases} \dfrac{V_{GS} - V_T}{2} = nV_{th} \\ \dfrac{K}{2}\left(2nV_{th}\right)^2 = I_{D0}\dfrac{W}{L}e^2 \end{cases}$$

$$\Rightarrow \begin{cases} V_{GS} = V_T + nV_{th} \\ I_{D0} = \dfrac{K'2(nV_{th})^2}{e^2} \end{cases}$$

Carateristica de iesire a tranzistorului MOS

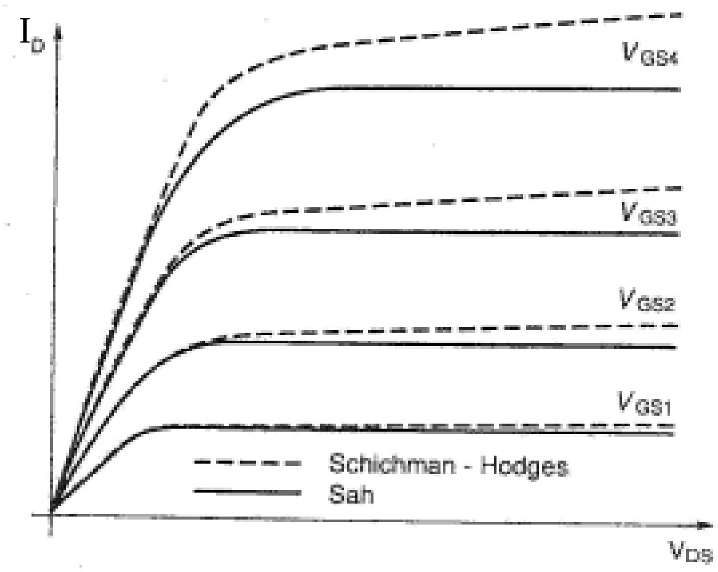


Efecte de ordin secundar:

a. Modularea lungimii canalului

$$I_D = \frac{K}{2}(V_{GS} - V_T)^2 (1 + \lambda V_{DS})$$

Modularea lungimii canalului



b. Degradarea mobilitatii

$$K = \frac{K_0}{[1 + \theta_G (V_{GS} - V_T)](1 + \theta_D V_{DS})}$$

c. Efectul de substrat

$$V_T = V_{T0} + \gamma\left(\sqrt{\Phi - V_{BS}} - \sqrt{\Phi}\right)$$

2. Modelul de semnal mic al tranzistorului MOS

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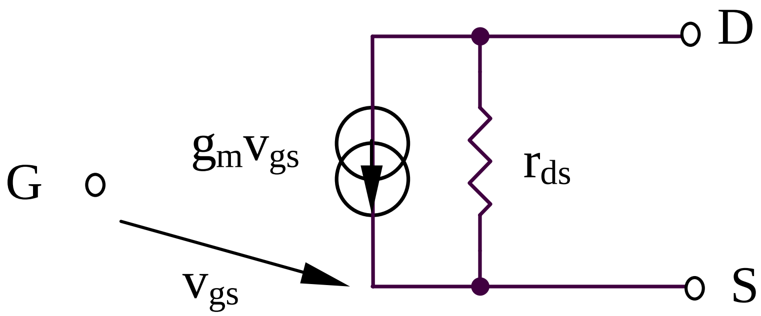

$$g_m = \frac{\partial I_D}{\partial V_{GS}}$$

$$r_{ds} = \frac{1}{g_{ds}} = \frac{1}{\dfrac{\partial I_D}{\partial V_{DS}}}$$

$$\left.\begin{aligned} g_m &= \frac{\partial I_D}{\partial V_{GS}} \cong K(V_{GS} - V_T) \\ I_D &= \frac{K}{2}(V_{GS} - V_T)^2 \Rightarrow V_{GS} - V_T = \sqrt{\frac{2I_D}{K}} \end{aligned}\right\} \Rightarrow g_m = \sqrt{2KI_D}$$

$$r_{ds} = \frac{1}{\dfrac{\partial I_D}{\partial V_{DS}}} = \frac{1}{\dfrac{K}{2}(V_{GS} - V_T)^2 \lambda} \cong \frac{1}{\lambda I_D}$$

Exemplu

$$I_D = 1mA, \lambda = 10^{-3}V^{-1}, K = 5 \times 10^{-4} A/V^2$$

$$\Rightarrow g_m = \sqrt{2KI_D} = 1mA/V$$

$$r_{ds} = \frac{1}{\lambda I_D} = 1M\Omega$$

3. Modelul de inalta frecventa

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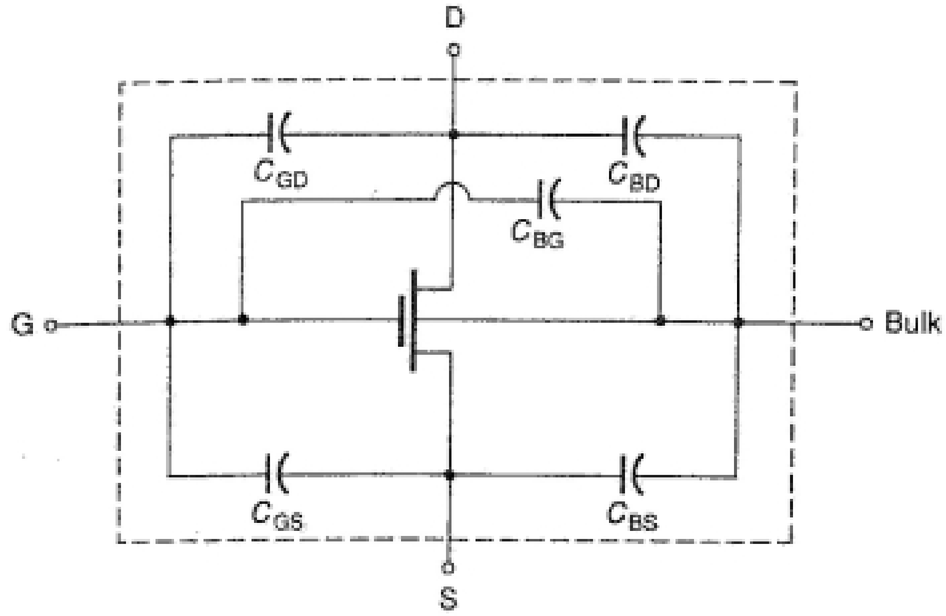

4. Rezistente dinamice

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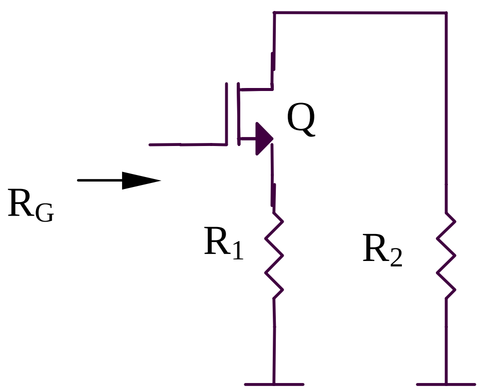
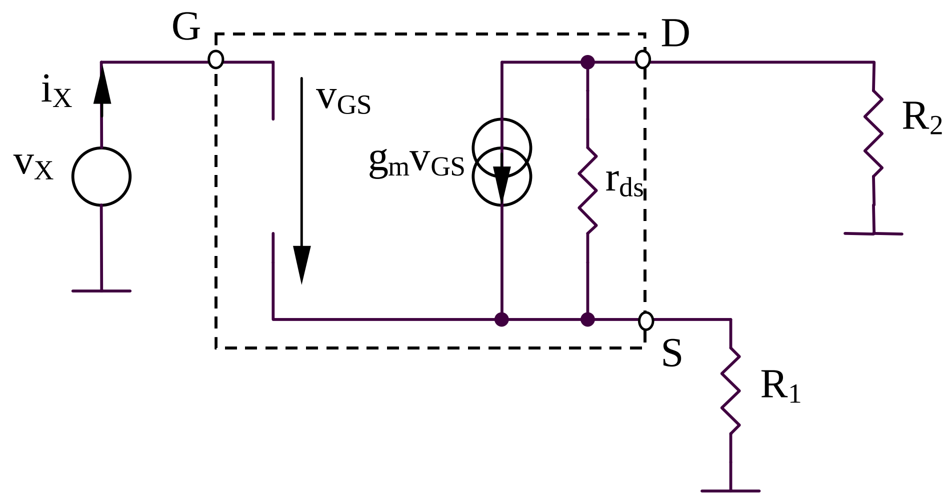
Rezistenta in poarta

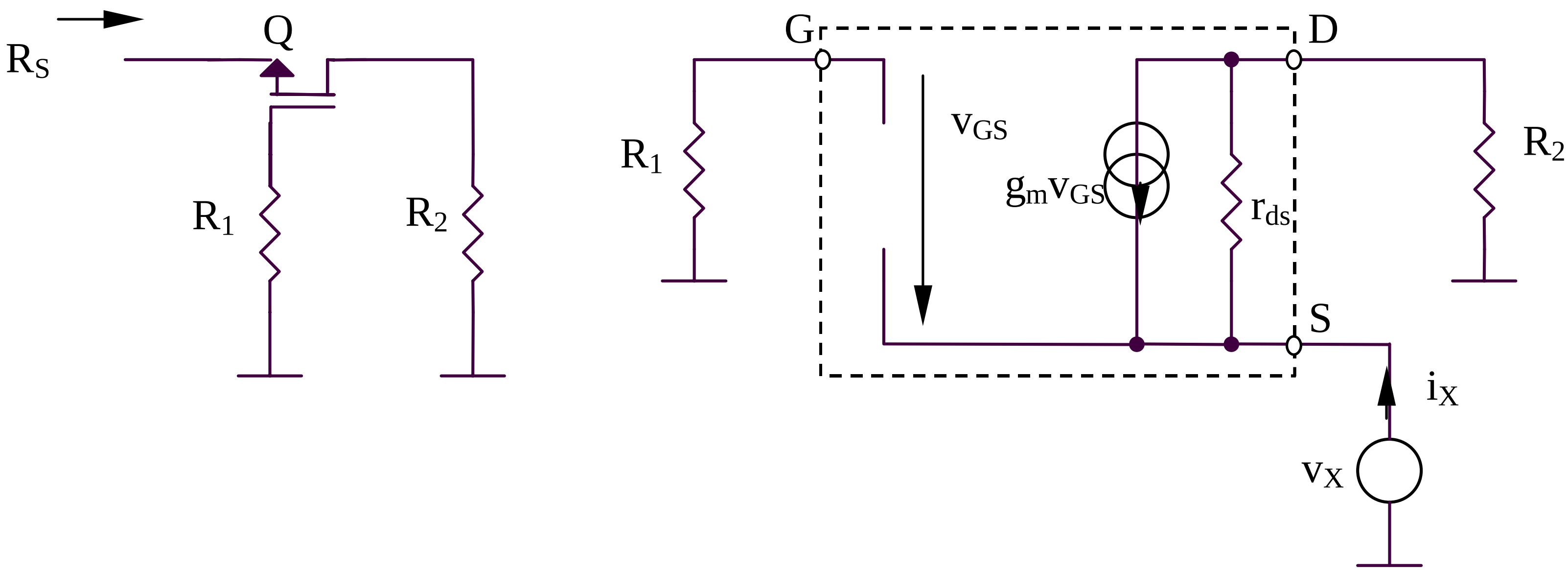




$$R_G = \infty$$

4. Rezistente dinamice

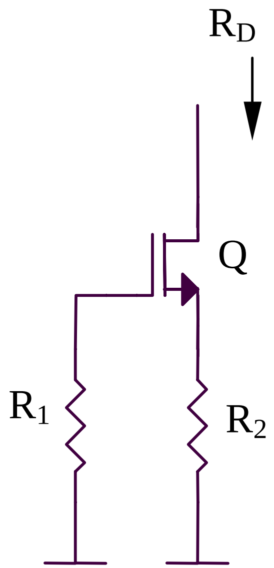
Rezistenta in sursa

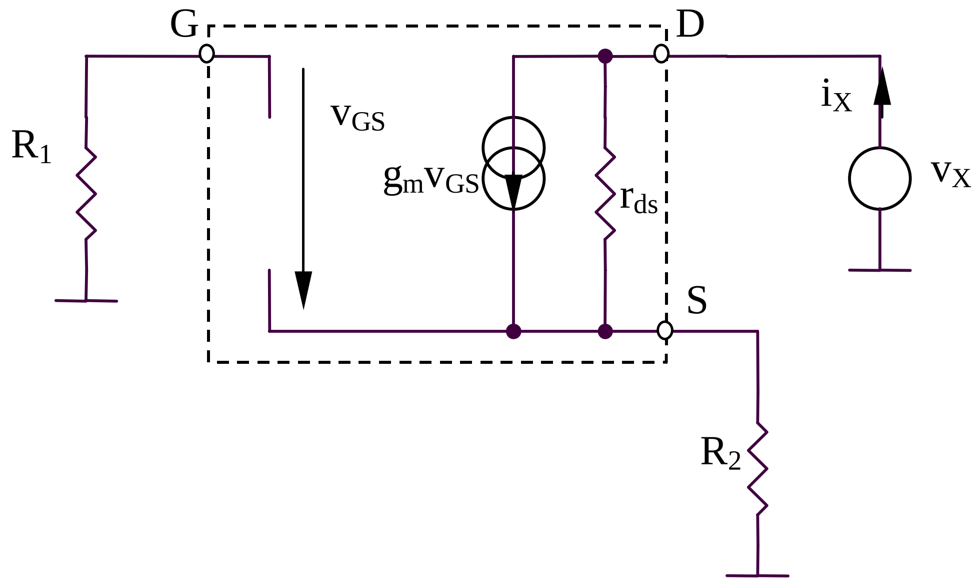


$$i_x \cong -g_m v_{gs} = g_m v_x \Rightarrow R_S = \frac{v_x}{i_x} = \frac{1}{g_m}$$

4. Rezistente dinamice

Rezistenta in drena





$$\left.\begin{aligned} v_x &= \left(i_x - g_m v_{gs}\right) r_{ds} + i_x R_2 \\ v_{gs} &= -i_x R_2 \end{aligned}\right\} \Rightarrow R_D = \frac{v_x}{i_x} = r_{ds}\left(1 + g_m R_2\right) + R_2 \cong r_{ds}\left(1 + g_m R_2\right)$$

5. Etaje de amplificare elementare

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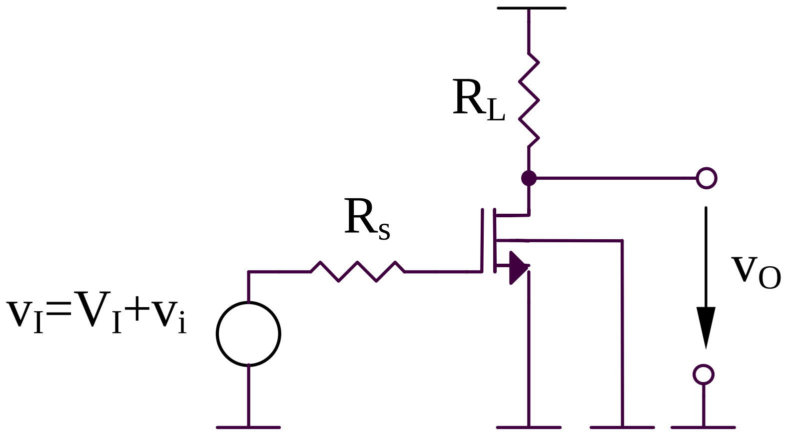
Amplificatorul sursa comuna



$$A_v = \frac{v_O}{v_I} = \frac{-g_m v_{GS}(R_L // r_{ds})}{v_{GS}}$$

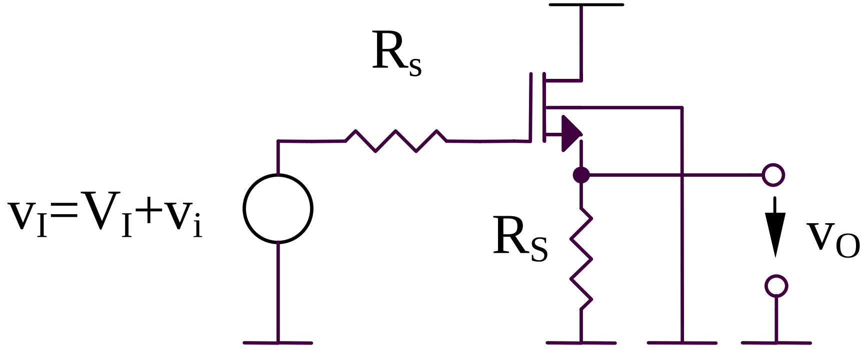
$$A_v = -g_m(R_L // r_{ds})$$

$$R_i = \infty$$

$$R_o = R_L // r_{ds}$$

5. Etaje de amplificare elementare

Amplificatorul drena comuna



$$A_v = \frac{v_O}{v_I} = \frac{g_m v_{GS} R_s}{v_{GS} + g_m v_{GS} R_s}$$

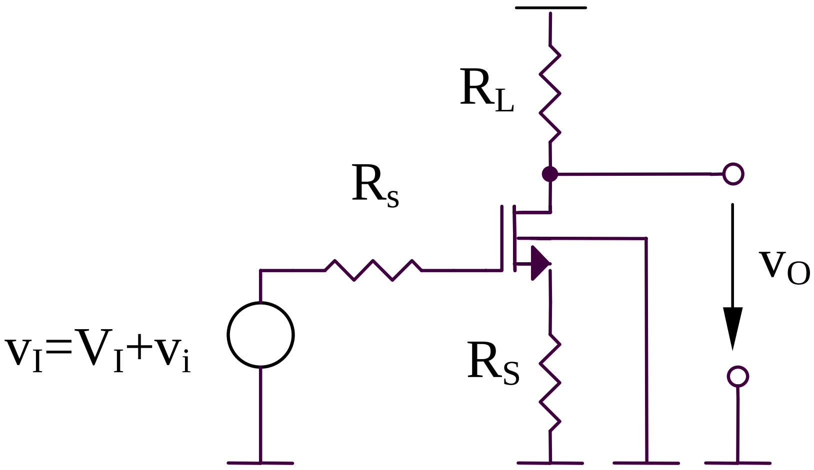
$$A_v = \frac{g_m R_s}{1 + g_m R_s} \cong 1$$

$$R_i = \infty$$

$$R_o = \frac{1}{g_m} // R_s$$

5. Etaje de amplificare elementare

Amplificatorul sarcina distribuita



$$A_v = \frac{v_O}{v_I} = \frac{-g_m v_{GS} R_L}{v_{GS} + g_m v_{GS} R_s}$$

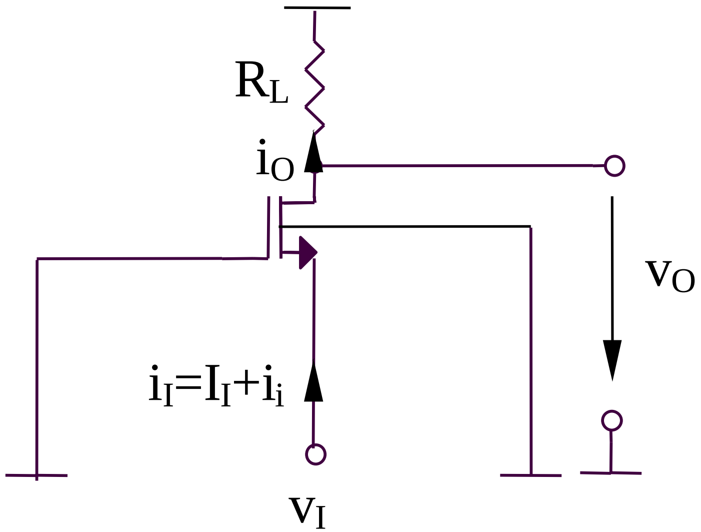
$$A_v = -\frac{g_m R_L}{1 + g_m R_s}$$

$$R_i = \infty$$

$$R_o \cong R_L$$

5. Etaje de amplificare elementare

Amplificatorul grila comuna



$$A_v = \frac{v_O}{v_I} = \frac{-g_m v_{GS} R_L}{-v_{GS}}$$

$$A_v = g_m R_L$$

$$R_i = \frac{1}{g_m}$$

$$R_o = R_L // r_{ds}$$