

Circuite integrate analogice

Structura cursului

- 1. Modelarea dispozitivelor bipolare si MOS**
- 2. Aplicatii ale amplificatoarelor operationale**
- 3. Surse de curent si surse de tensiune**
- 4. Amplificatoare elementare**
- 5. Etaje de iesire**
- 6. Amplificatoare operationale. Structuri interne**
- 7. Raspunsul in frecventa al circuitelor.**
Stabilitatea circuitelor cu reactie
- 8. Structuri analogice liniare**
- 9. Structuri neliniare de calcul analogic**

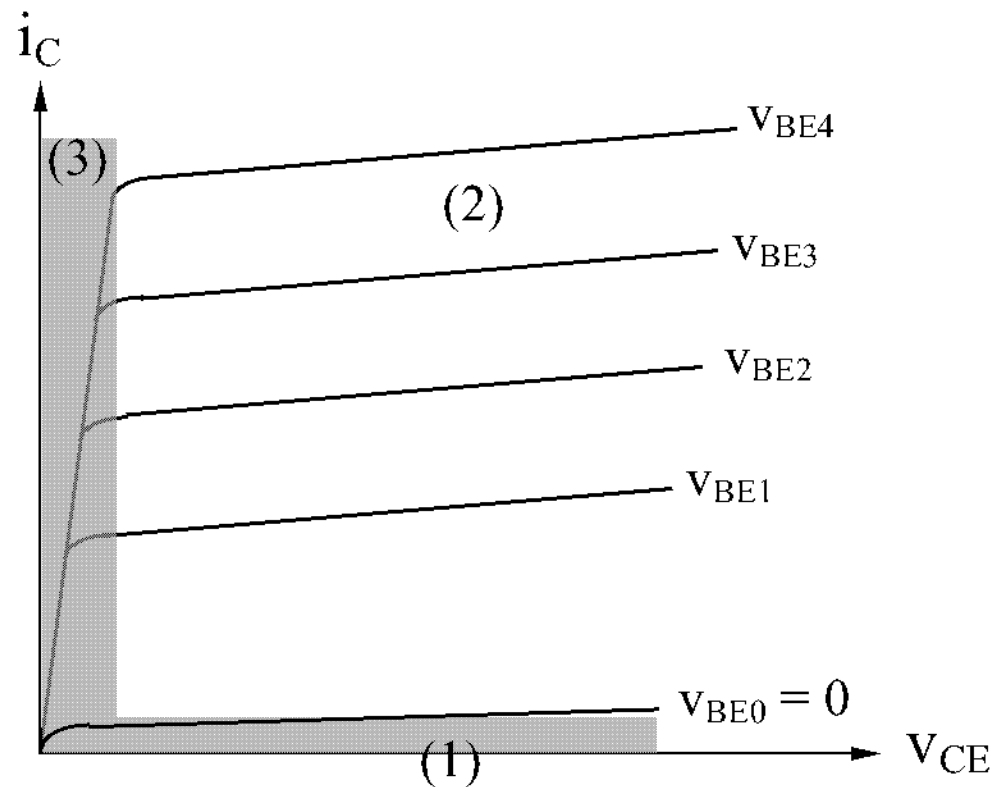
Capitolul 1

Modelarea dispozitivelor bipolare si MOS

1.1. Relatii fundamentale ale tranzistorului bipolar

Domenii de functionare:

- Regiunea de blocare (1)
- Regiunea activa normala (2)
- Regiunea de saturatie (3)



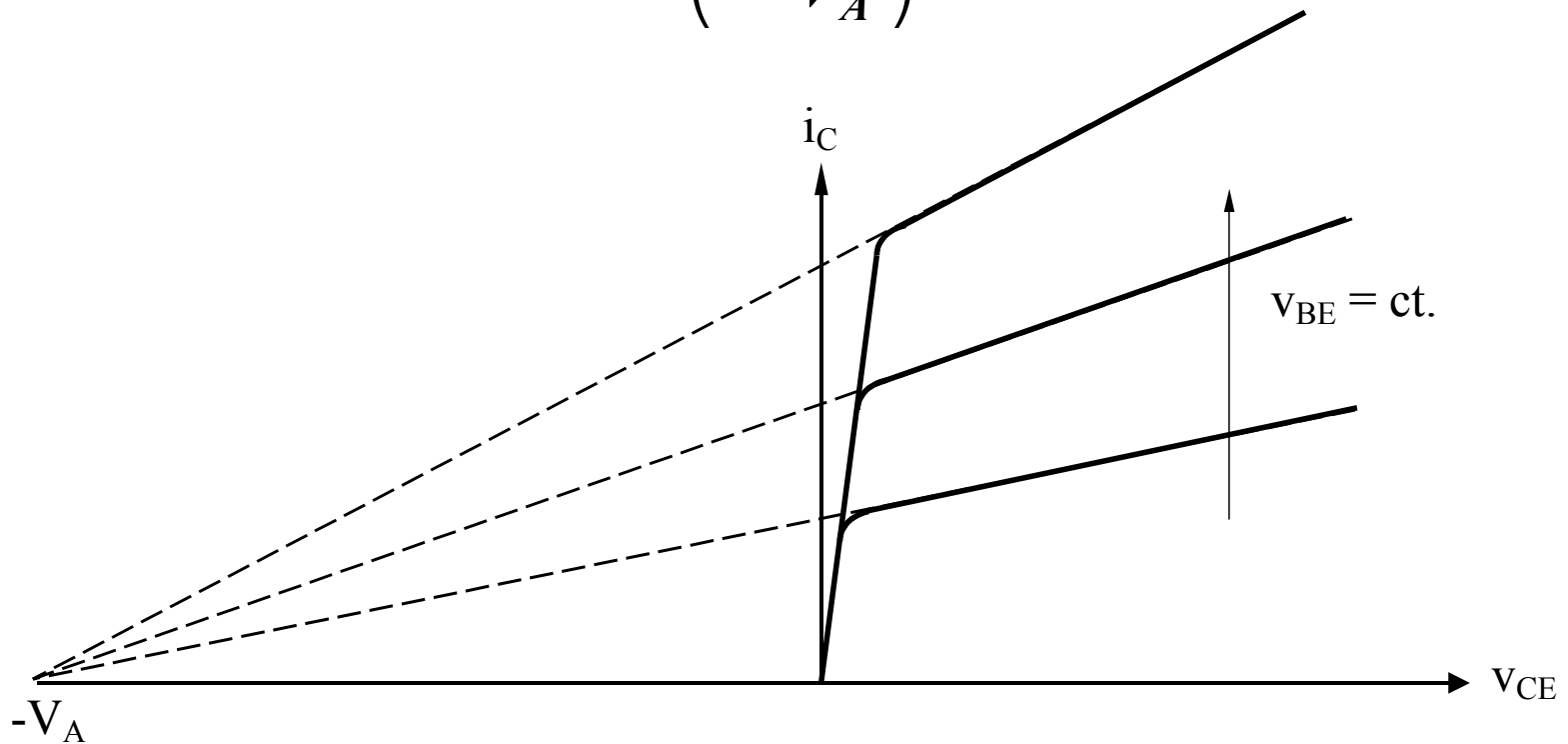
1.1.1. Functionarea la semnal mare

Regim activ normal:

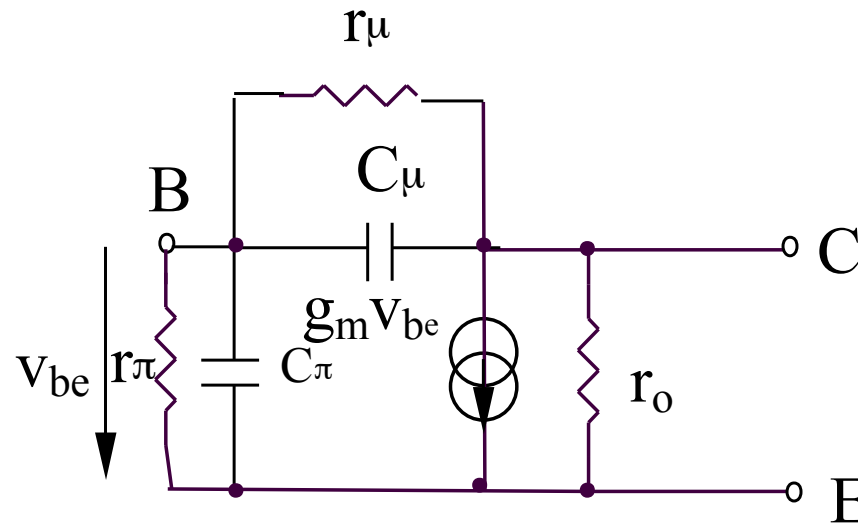
$$i_c = I_S \left(e^{\frac{v_{BE}}{V_{th}}} - 1 \right) \cong I_S e^{\frac{v_{BE}}{V_{th}}}$$

Efectul Early:

$$i_c = I_S e^{\frac{v_{BE}}{V_{th}}} \left(1 + \frac{v_{CE}}{V_A} \right)$$



1.1.2. Modelul de semnal mic (regim activ normal)



Conductanta de transfer:

$$\left. \begin{aligned} g_m &= \frac{\partial I_C}{\partial V_{BE}} \\ I_C &\cong I_S \exp\left(\frac{V_{BE}}{V_{th}}\right) \end{aligned} \right\} \Rightarrow g_m = I_S \exp\left(\frac{V_{BE}}{V_{th}}\right) \frac{1}{V_{th}} = \frac{I_C}{V_{th}} \cong 40 I_C$$

Rezistenta de iesire:

$$r_o = \frac{1}{g_o} = \frac{1}{\frac{\partial I_C}{\partial V_{CE}}} \left. \vphantom{r_o} \right\} \Rightarrow r_o = \frac{1}{I_S \exp\left(\frac{V_{BE}}{V_{th}}\right) \frac{1}{V_A}} \cong \frac{V_A}{I_C}$$
$$I_C = I_S \exp\left(\frac{V_{BE}}{V_{th}}\right) \left(1 + \frac{V_{CE}}{V_A}\right)$$

Rezistenta r_π :

$$r_\pi = \frac{\beta}{g_m}$$

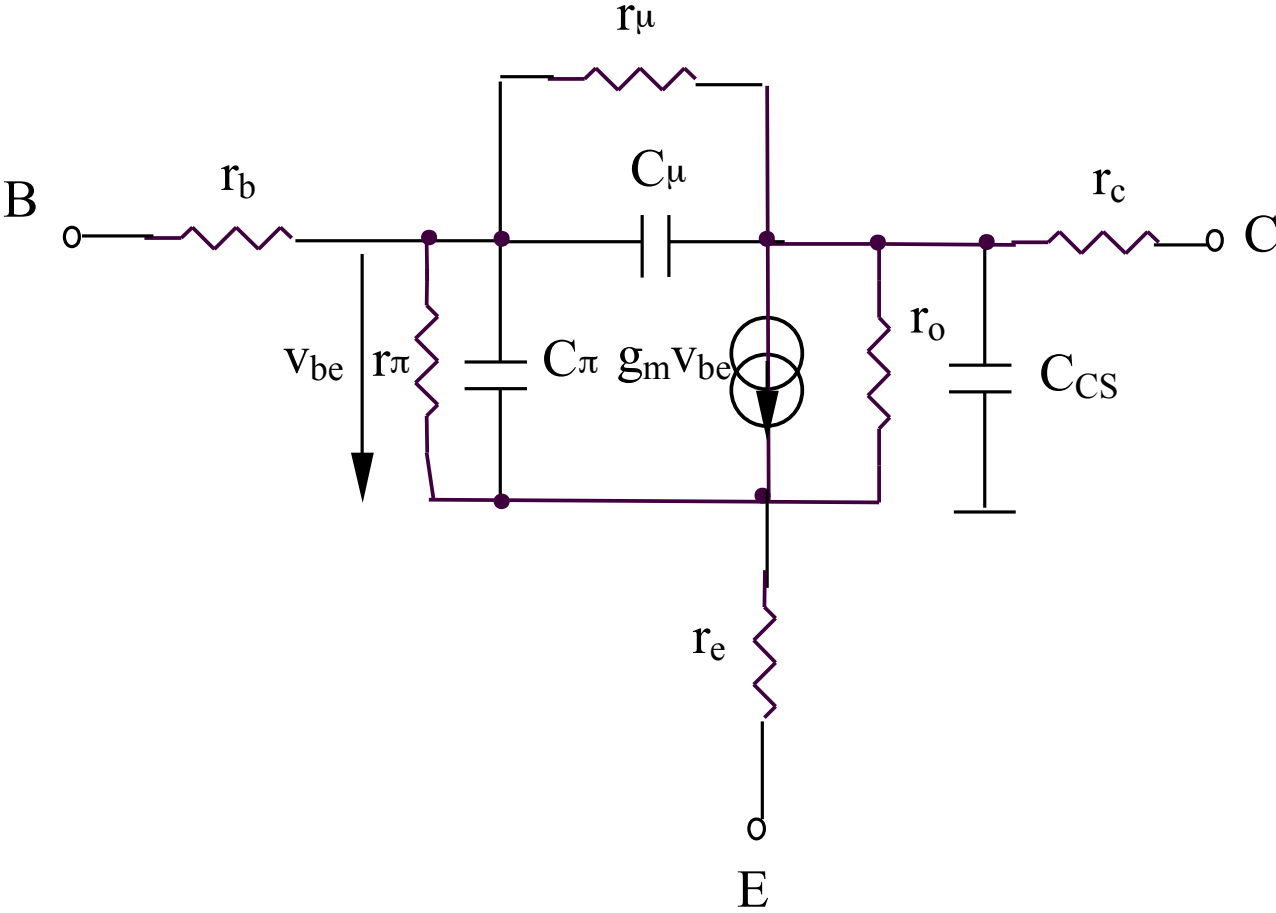
Rezistenta r_μ :

$$r_\mu = K\beta r_o$$

$K \geq 10$ pt. NPN

$K = 2 - 5$ pt. PNP

Circuit echivalent cu rezistente serie

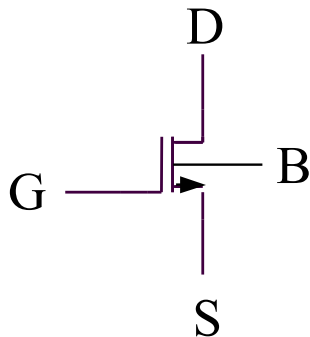


1.2. Relatii fundamentale ale tranzistorului MOS

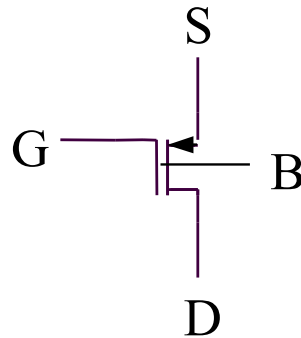
1.2.1. Modelul de semnal mare

Simboluri:

NMOS



PMOS



Notatii:

G = grila (poarta)

D = drena

S = sursa

B = substrat (bulk)

W/L = factor de aspect

K' = parametru transconductanta

V_T = tensiune de prag

V_{GS} = tensiune grila-sursa

V_{DS} = tensiune drena-sursa

I. Regiunea de inversie puternica

$$V_{GS} > V_T$$

a. Saturatie

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

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

b. Regiunea liniara

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

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

II. Regiunea de inversie slaba

$$V_{GS} < V_T$$

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

$$I_D|_{sat} = I_D|_{w.i.}$$

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

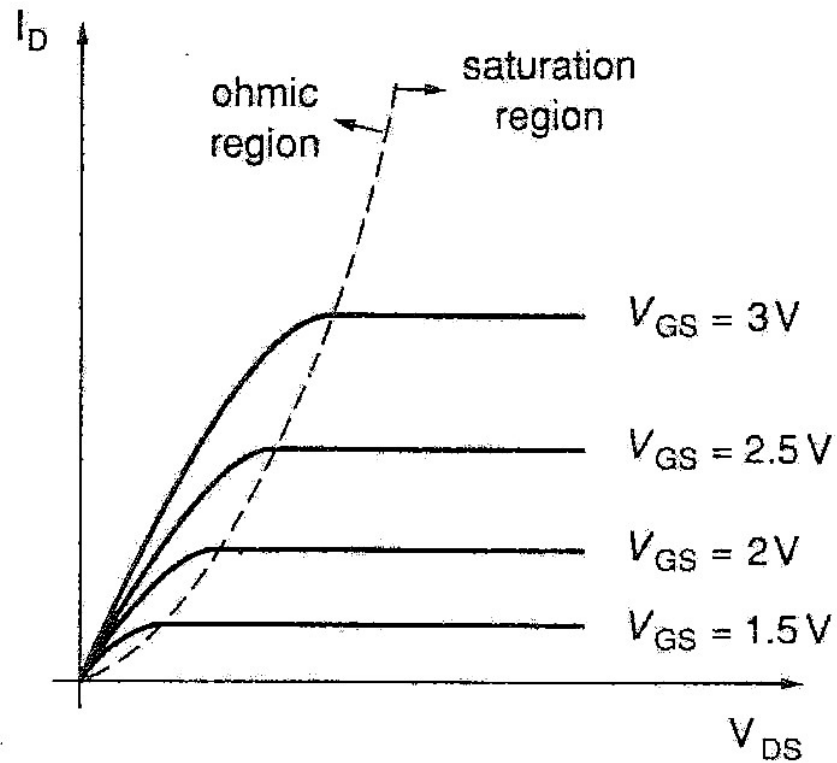
$$\frac{K}{2} (V_{GS} - V_T)^2 = I_{D0} \frac{W}{L} \exp\left(\frac{V_{GS} - V_T}{nV_{th}}\right)$$

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

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

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

Caracteristicile de iesire ale tranzistorului MOS



Efectele de ordin secundar:

a. Modularea lungimii canalului

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

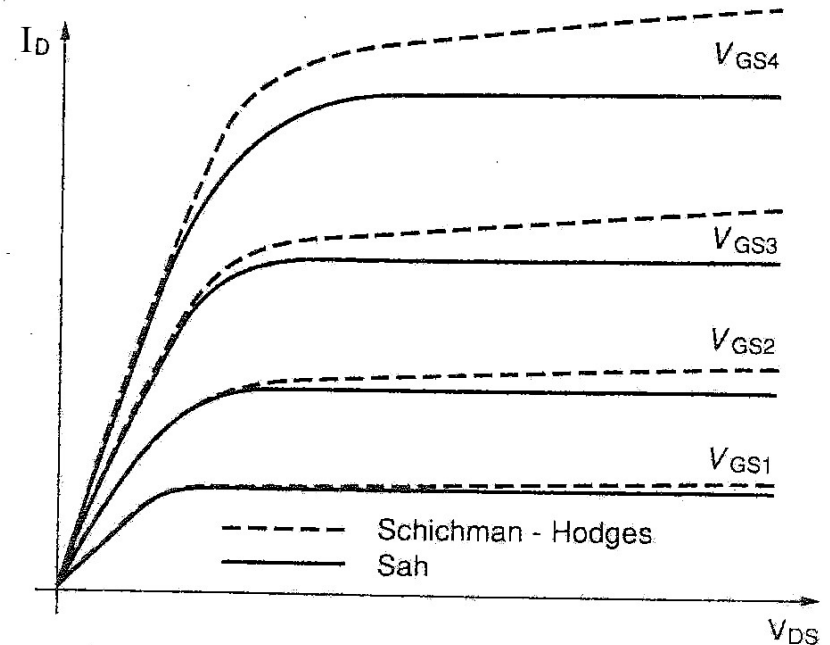
b. Degradarea mobilitatii

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

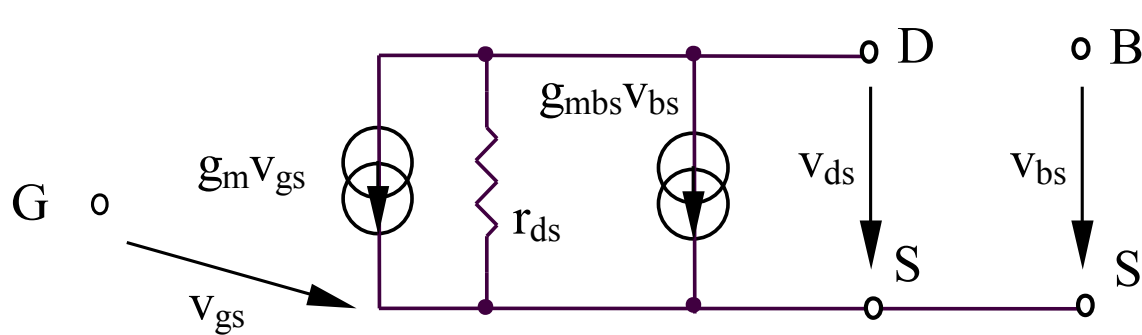
c. Efectul de substrat

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

Modularea lungimii canalului



1.2.2. Modelul de semnal mic al tranzistorului MOS



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

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

$$g_m = \frac{\partial I_D}{\partial V_{GS}} \cong K(V_{GS} - V_T)$$

$$I_D = \frac{K}{2}(V_{GS} - V_T)^2 \Rightarrow V_{GS} - V_T = \sqrt{\frac{2I_D}{K}}$$

$$\Rightarrow g_m = \sqrt{2KI_D}$$

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

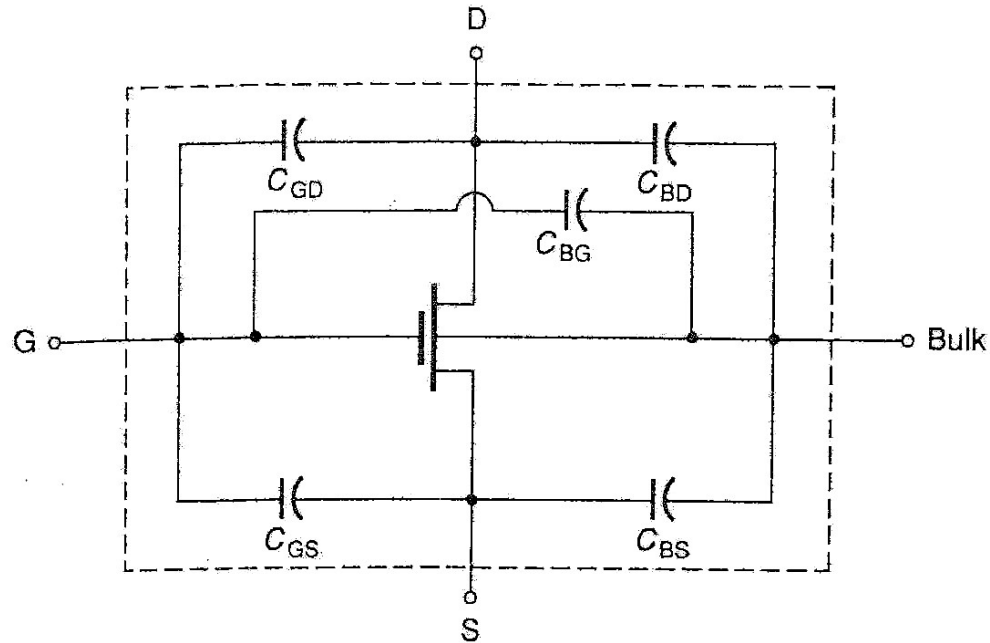
Exemplu

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

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

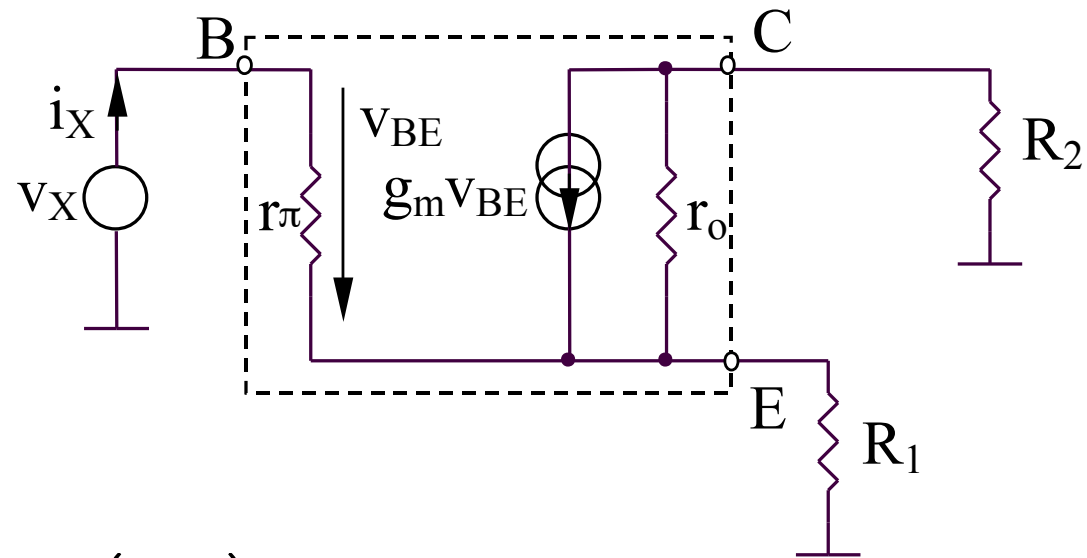
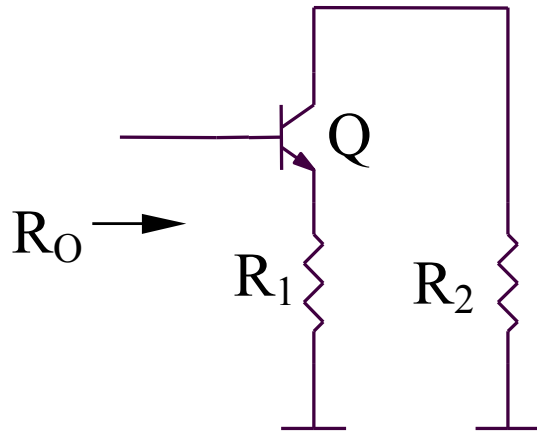
$$r_{ds} = \frac{1}{\lambda I_D} = 1\text{M}\Omega$$

Modelul de inalta frecventa



1.3. Rezistente dinamiche

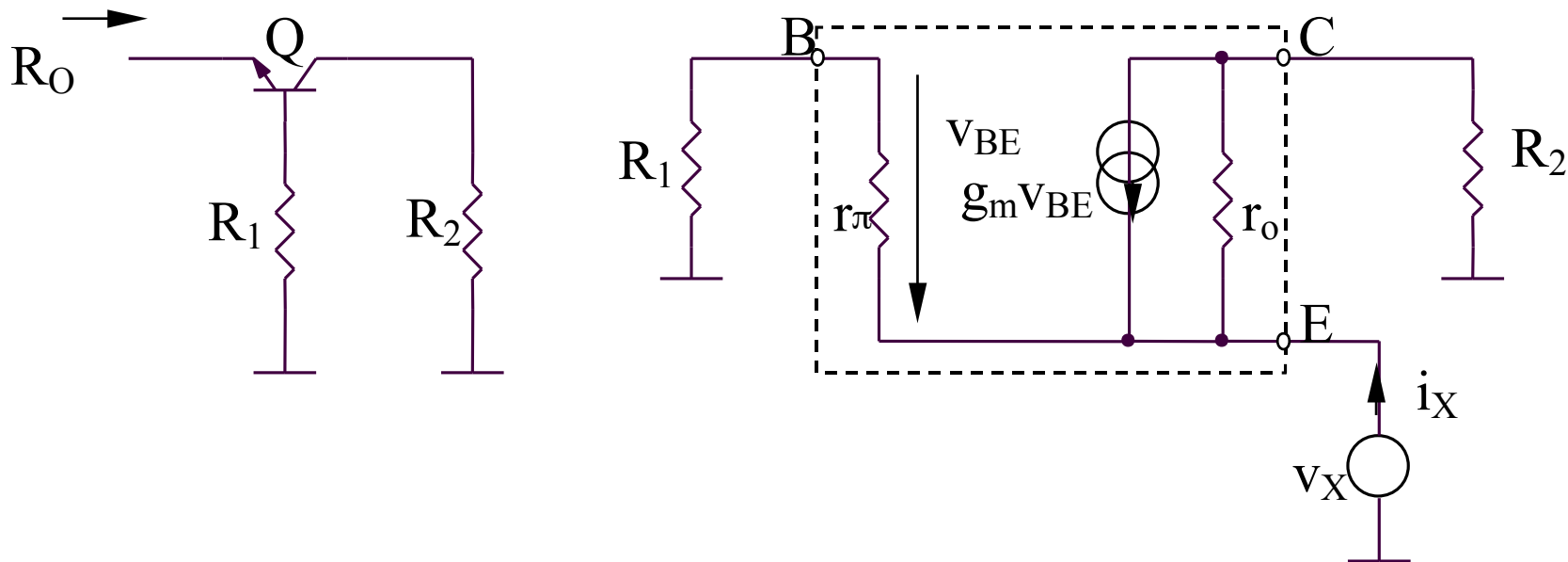
Rezistenta in baza



$$v_x = i_x r_\pi + (\beta + 1) i_x R_1$$

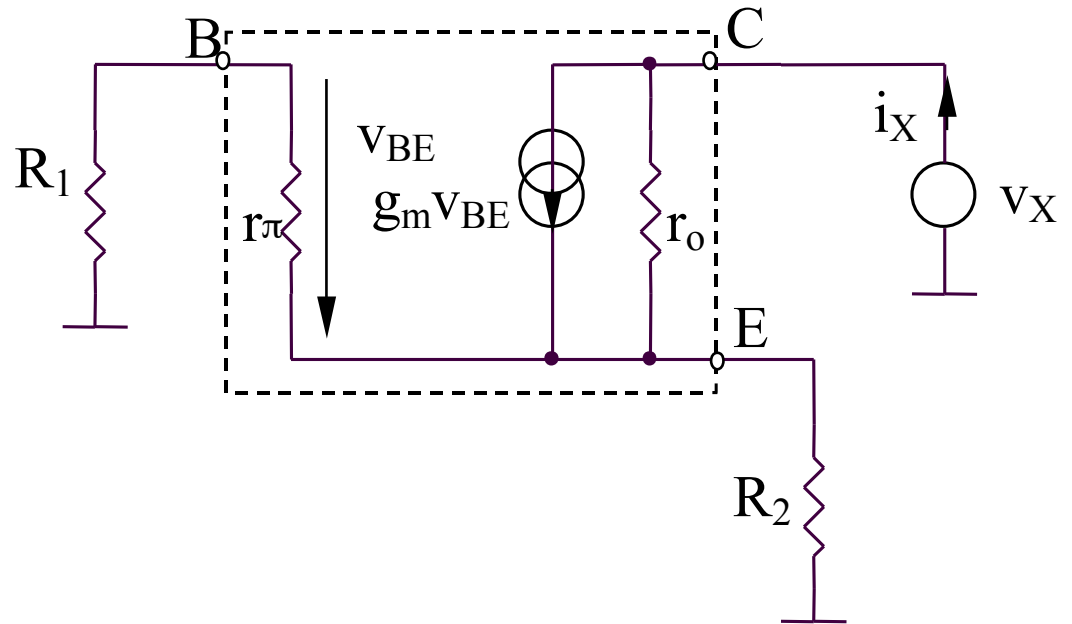
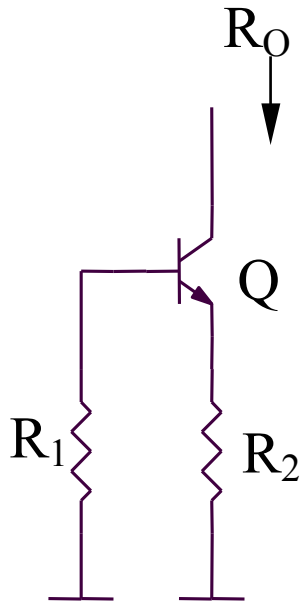
$$R_O = \frac{v_x}{i_x} = r_\pi + (\beta + 1) R_1$$

Rezistenta in emitor



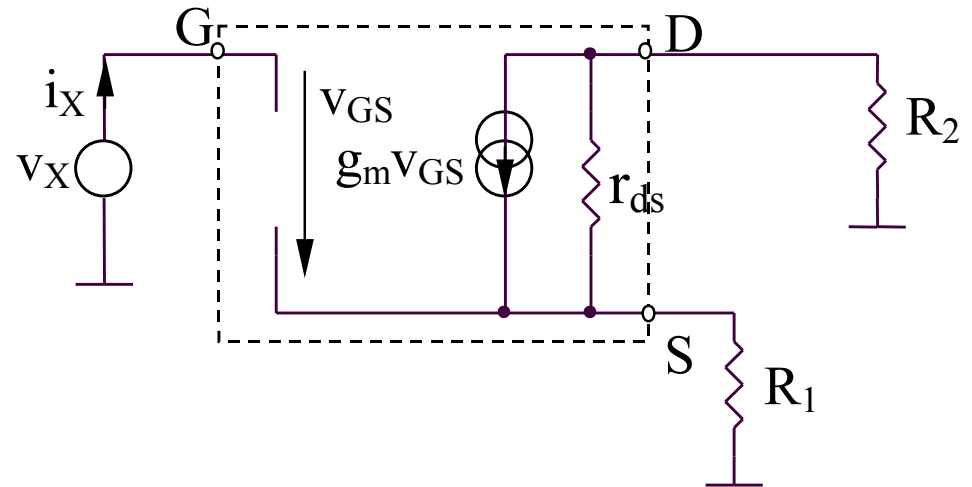
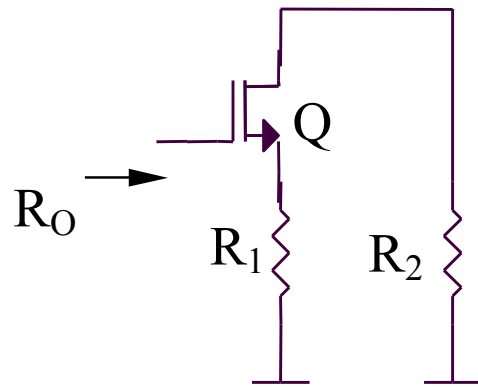
$$R_O = \frac{R_1 + r_\pi}{\beta + 1}$$

Rezistența în colector



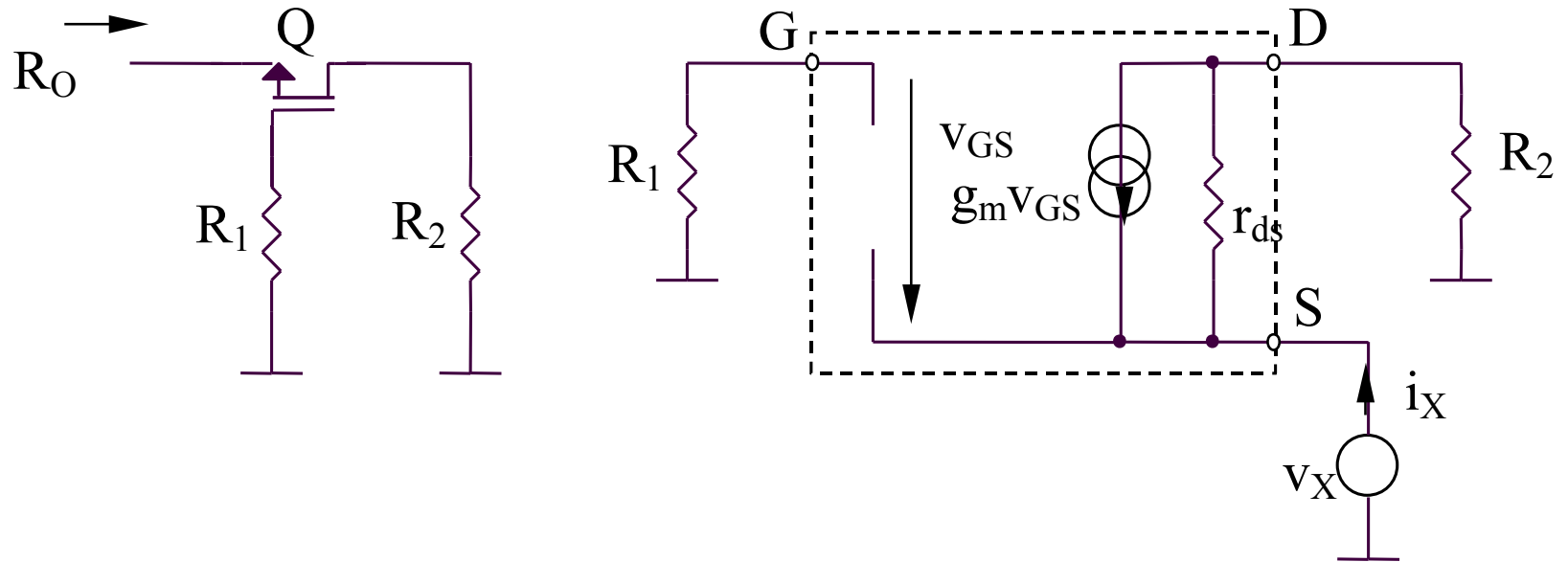
$$R_O = r_o \left(1 + \frac{\beta R_2}{r_\pi + R_1 + R_2} \right)$$

Rezistența în poarta



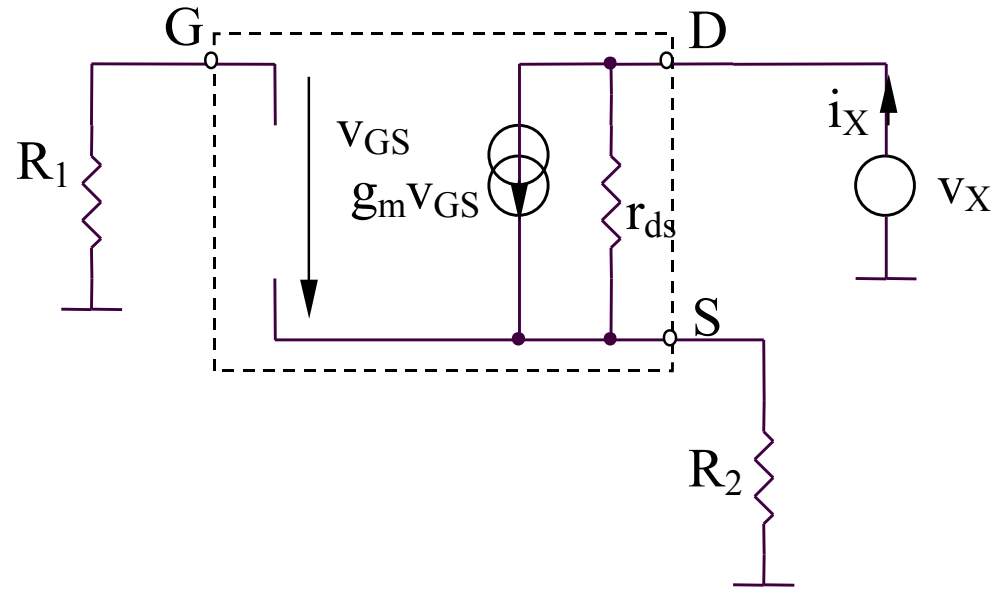
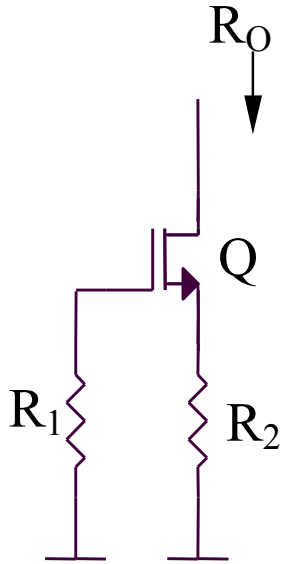
$$R_O = \infty$$

Rezistența în sursă



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

Rezistența în drena



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