

# **Circuite integrate analogice**

## **Structura cursului**

- 1. Modelarea dispozitivelor bipolare si MOS**
- 2. Circuite integrate analogice fundamentale**
- 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**

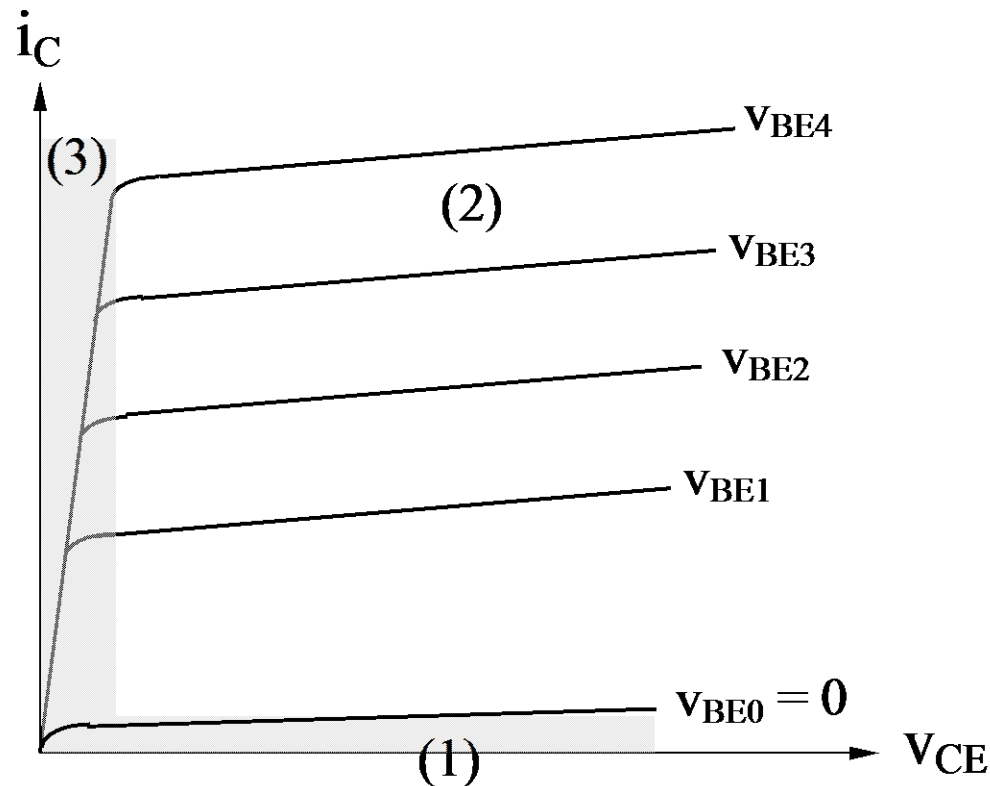
# **Capitolul 1**

## **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)



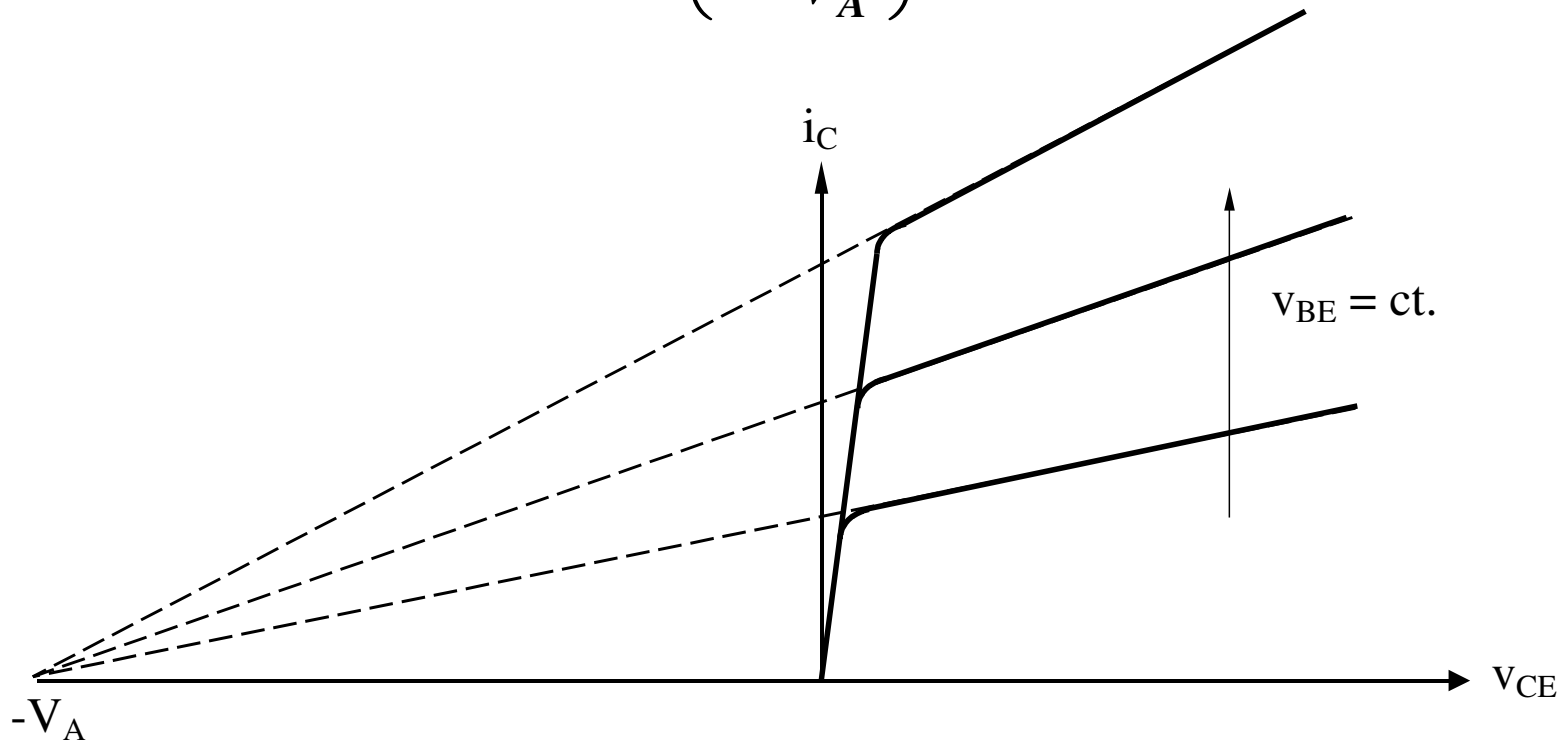
## 1.1.1. Functionarea la semnal mare

Regim activ normal:

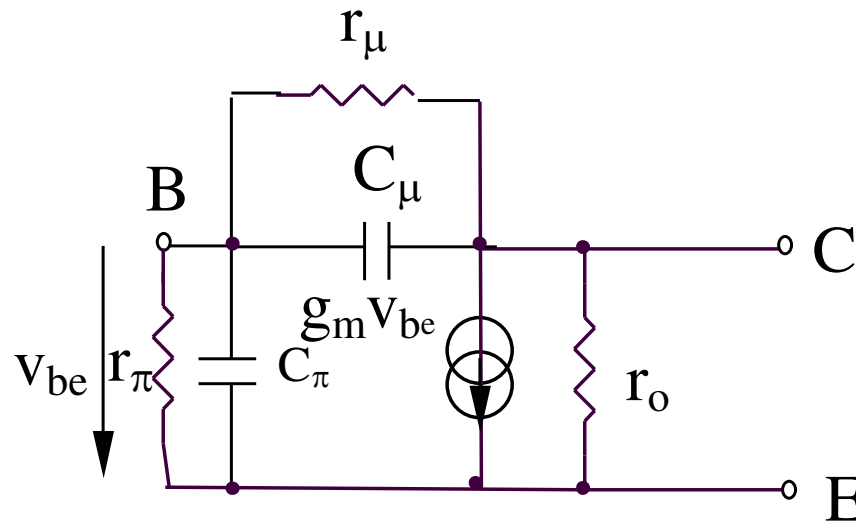
$$i_c = I_S \left( e^{\frac{v_{BE}}{V_{th}}} - 1 \right) \cong I_S e^{\frac{v_{BE}}{V_{th}}}$$

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:

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

Rezistența de ieșire:

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

Rezistența  $r_\pi$ :

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

Rezistența  $r_\mu$ :

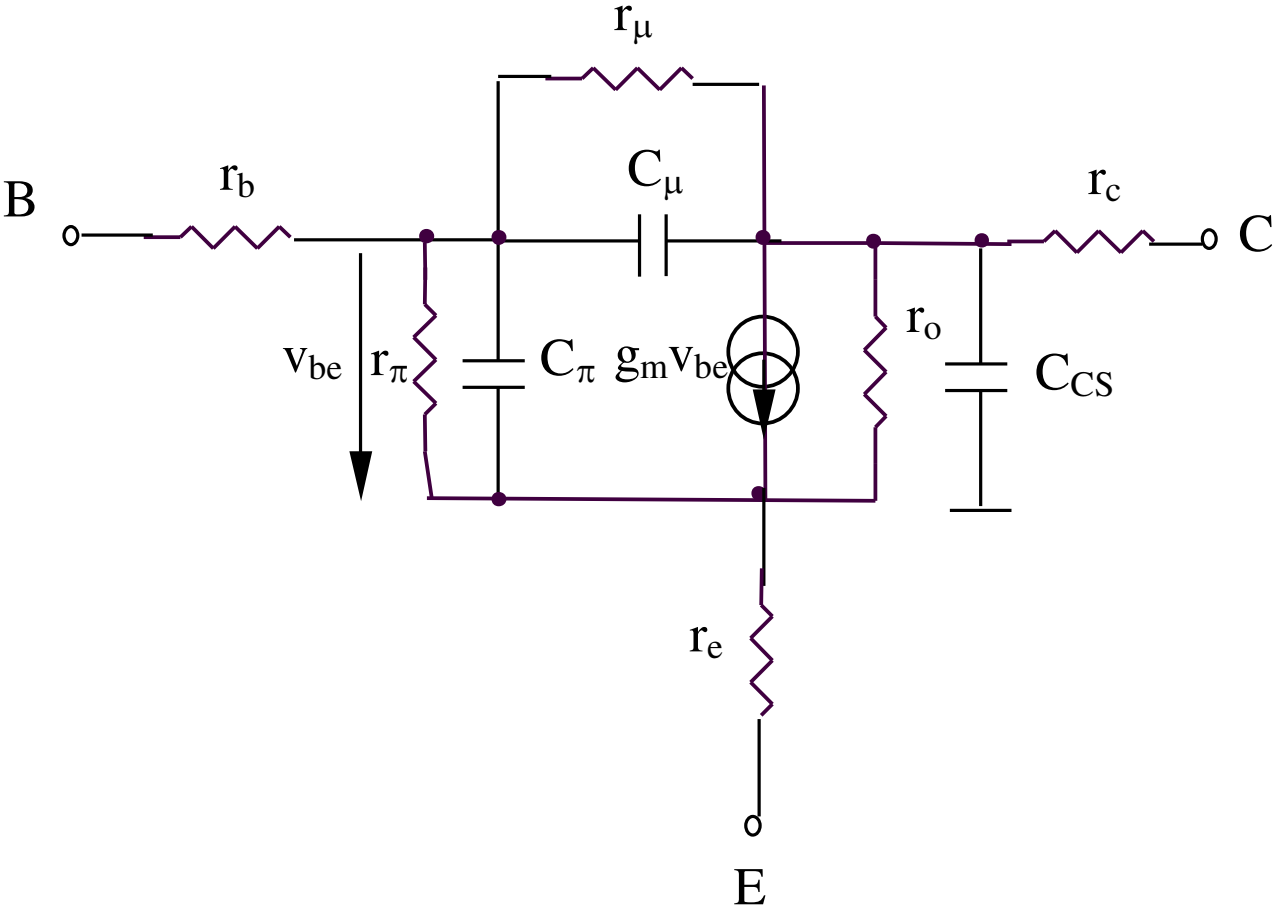
$$r_\mu = K\beta r_o$$

**$K \geq 10$  pt. NPN**

**$K = 2 - 5$  pt. PNP**



# Circuit echivalent cu rezistente serie

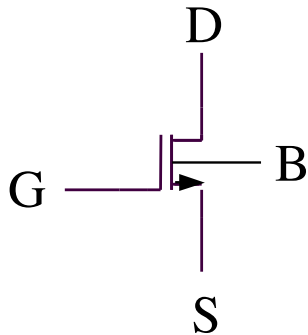


## **1.2. Relatii fundamentale ale tranzistorului MOS**

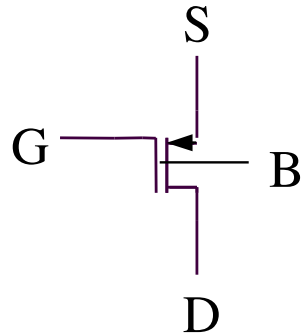
## 1.2.1. Modelul de semnal mare

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

$$V_{GS} < V_T$$

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

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

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

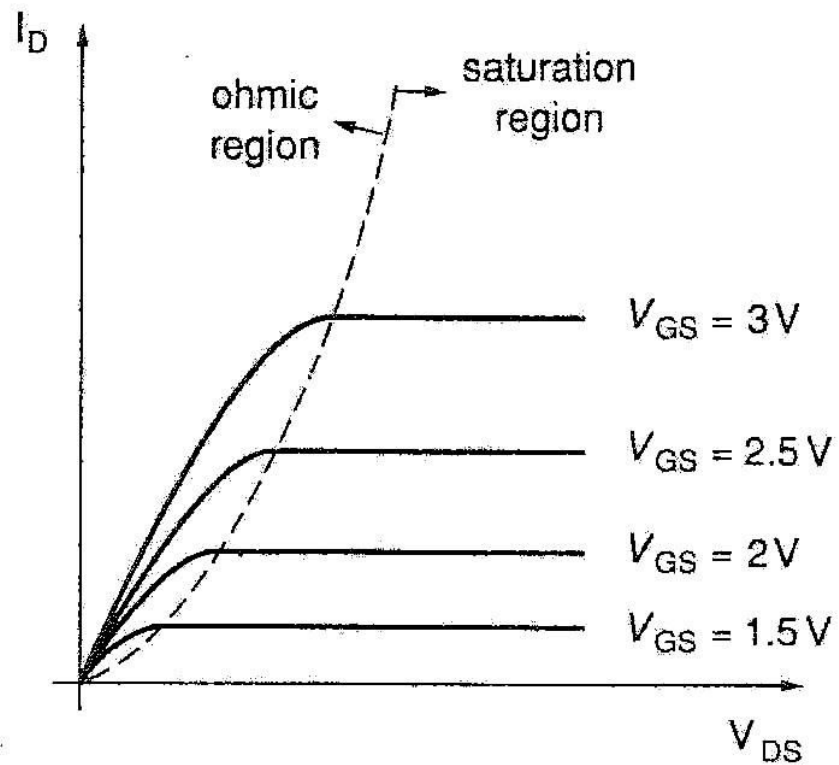
$$\frac{K}{2}(V_{GS} - V_T)^2 = I_{D0} \frac{W}{L} \exp\left(\frac{V_{GS} - V_T}{nV_{th}}\right)$$

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

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

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

# Caracteristicile de iesire ale tranzistorului MOS



## Efectele de ordin secundar:

### a. Modularea lungimii canalului

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

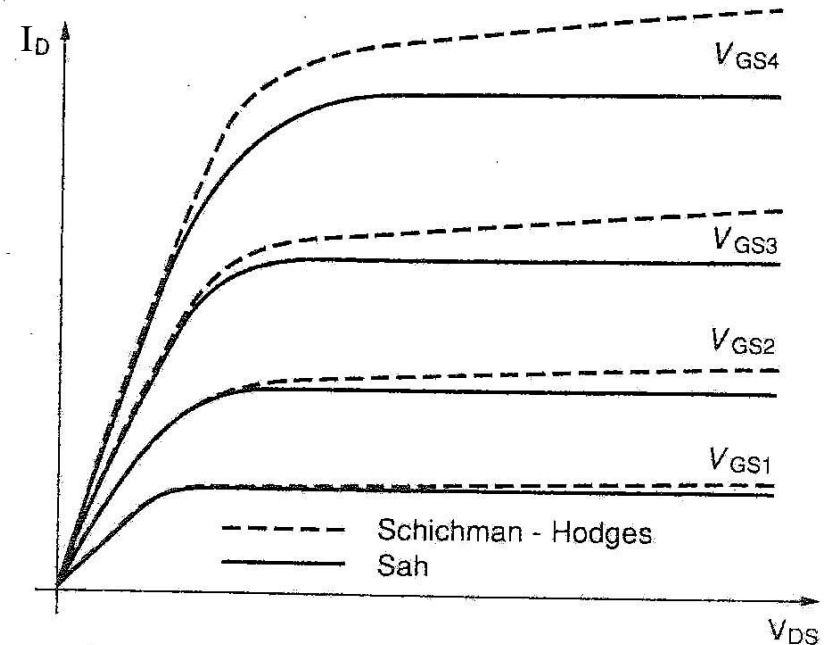
### b. Degradarea mobilitatii

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

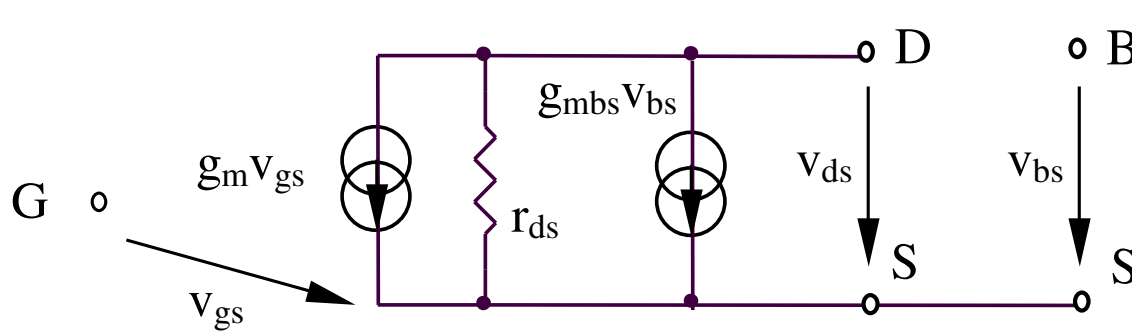
### c. Efectul de substrat

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

## Modularea lungimii canalului



## 1.2.2. Modelul de semnal mic al tranzistorului MOS



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

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

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

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

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

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



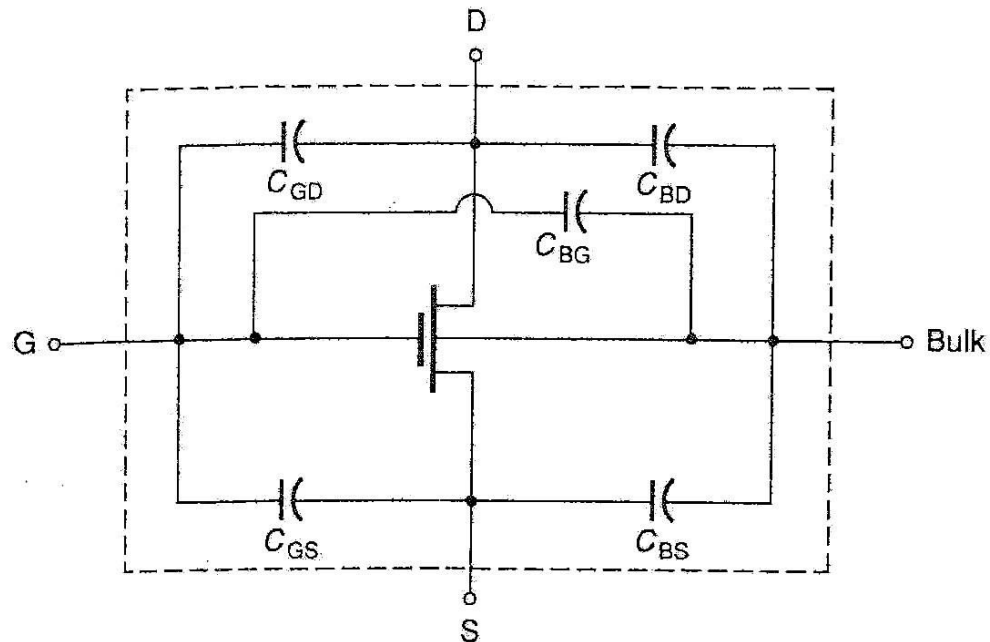
## Exemplu

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

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

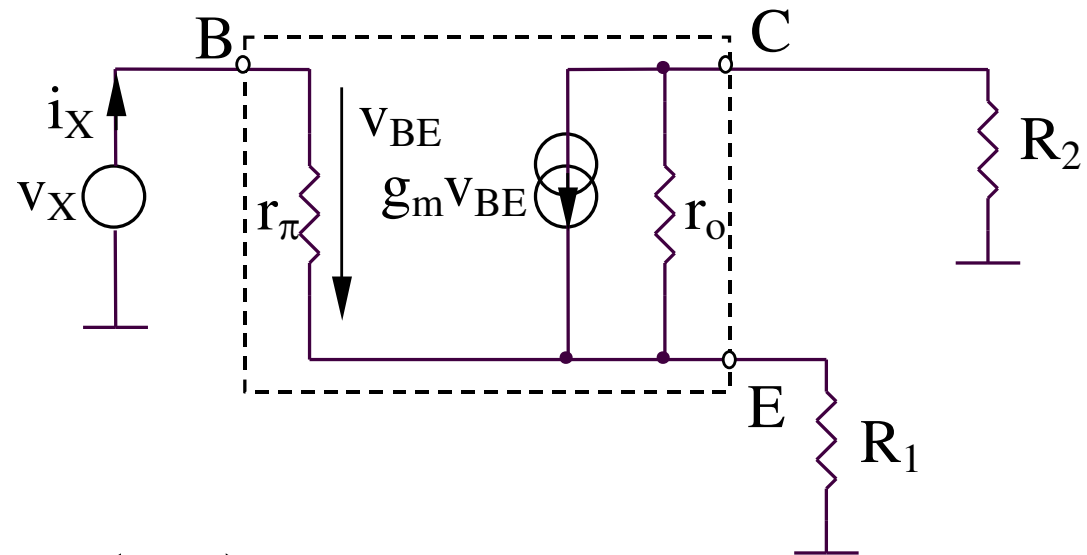
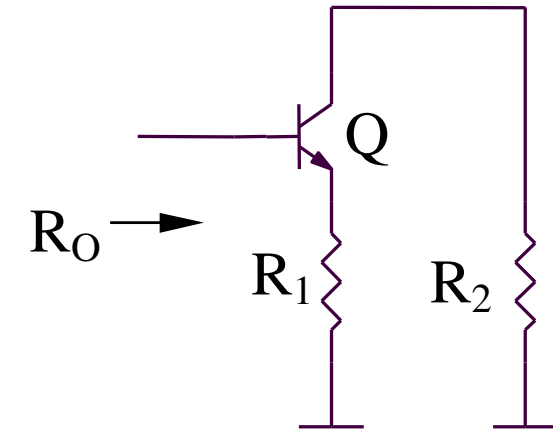
$$r_{ds} = \frac{1}{\lambda I_D} = 1\text{M}\Omega$$

## Modelul de inalta frecventa



## **1.3. Rezistente dinamiche**

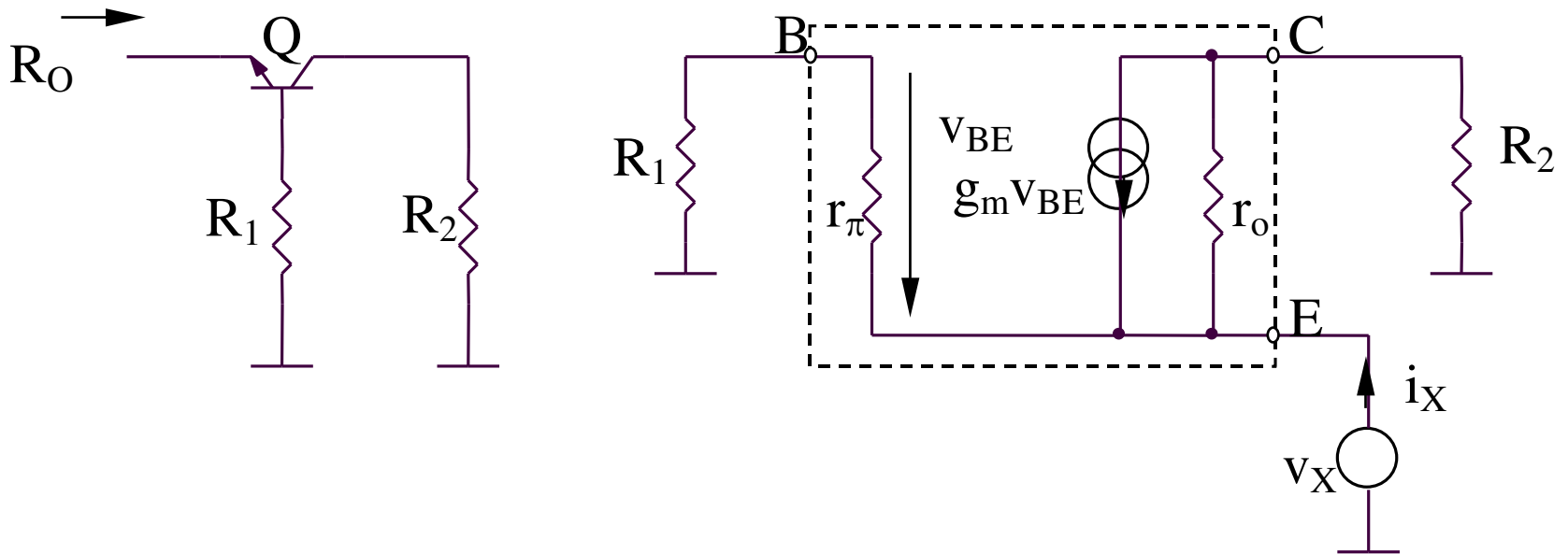
## Rezistenta in baza



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

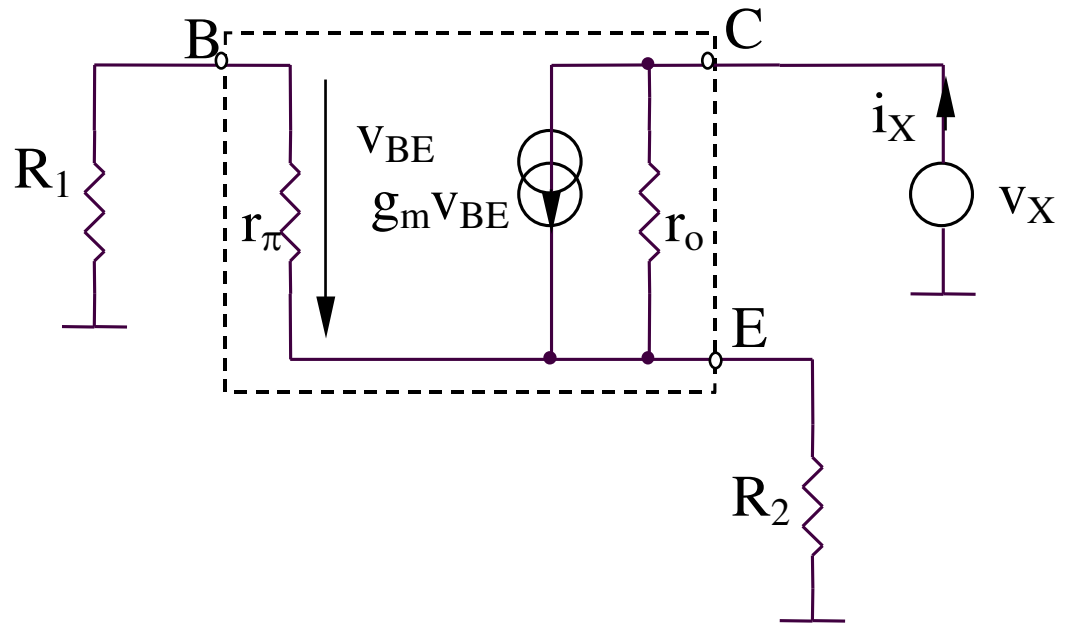
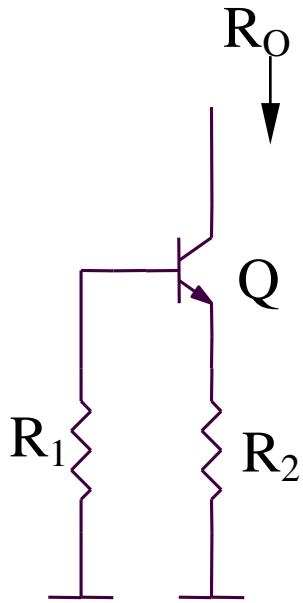
$$R_O = \frac{v_x}{i_x} = r_\pi + (\beta + 1) R_1$$

## Rezistența în emitor



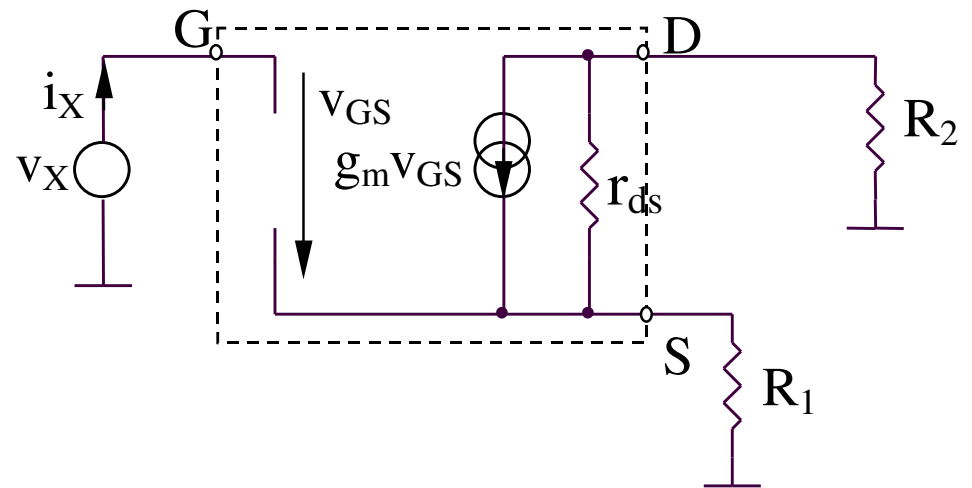
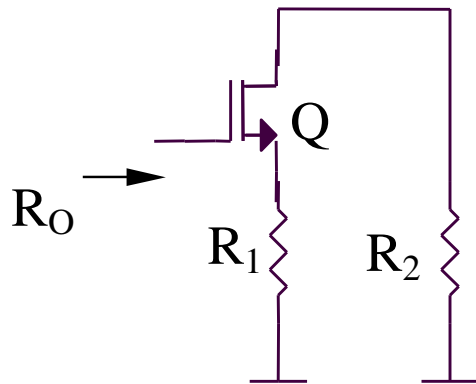
$$R_O = \frac{R_1 + r_\pi}{\beta + 1}$$

## Rezistența în colector



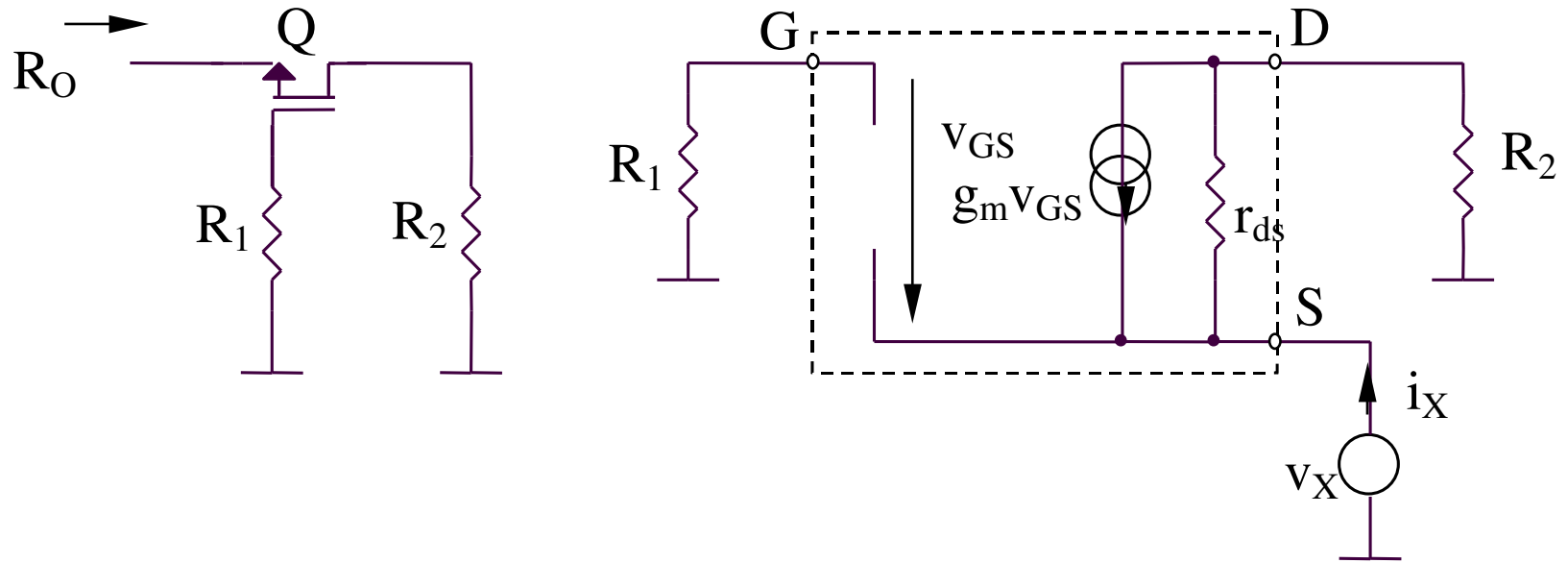
$$R_O = r_o \left( 1 + \frac{\beta R_2}{r_\pi + R_1 + R_2} \right)$$

## Rezistența în poarta



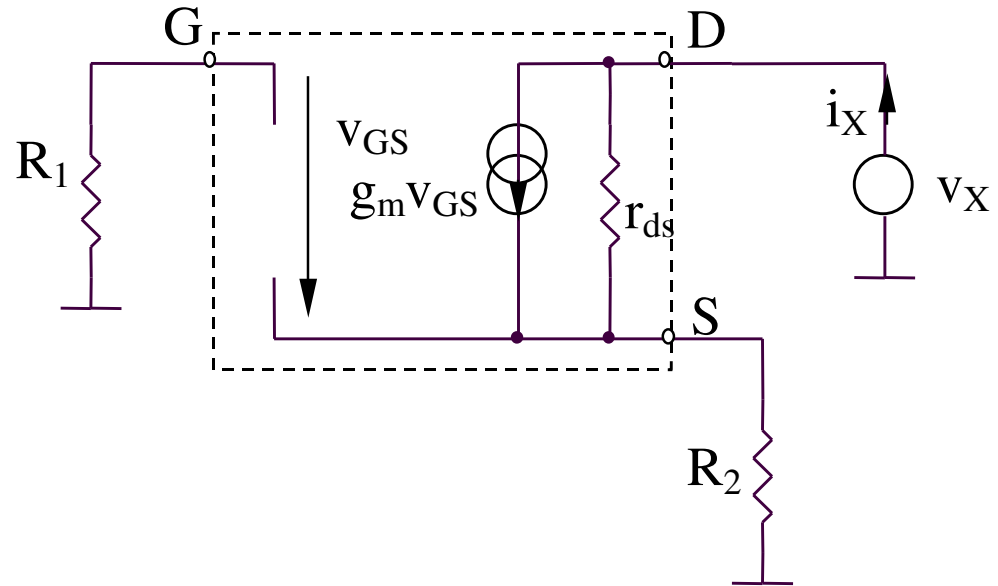
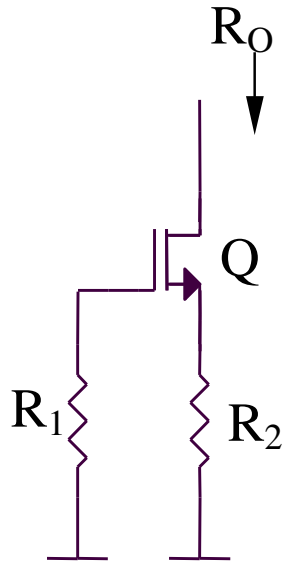
$$R_O = \infty$$

## 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



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