

# **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**

# **Capitolul 1**

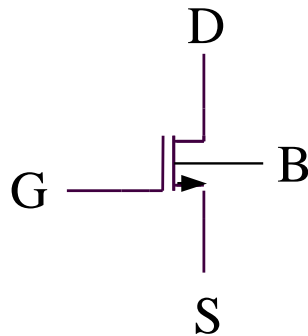
## **Modelarea dispozitivelor CMOS si bipolare**

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

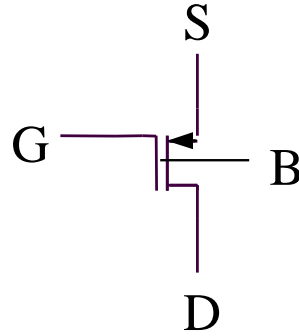
## 1.1.1. Modelul de semnal mare

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

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

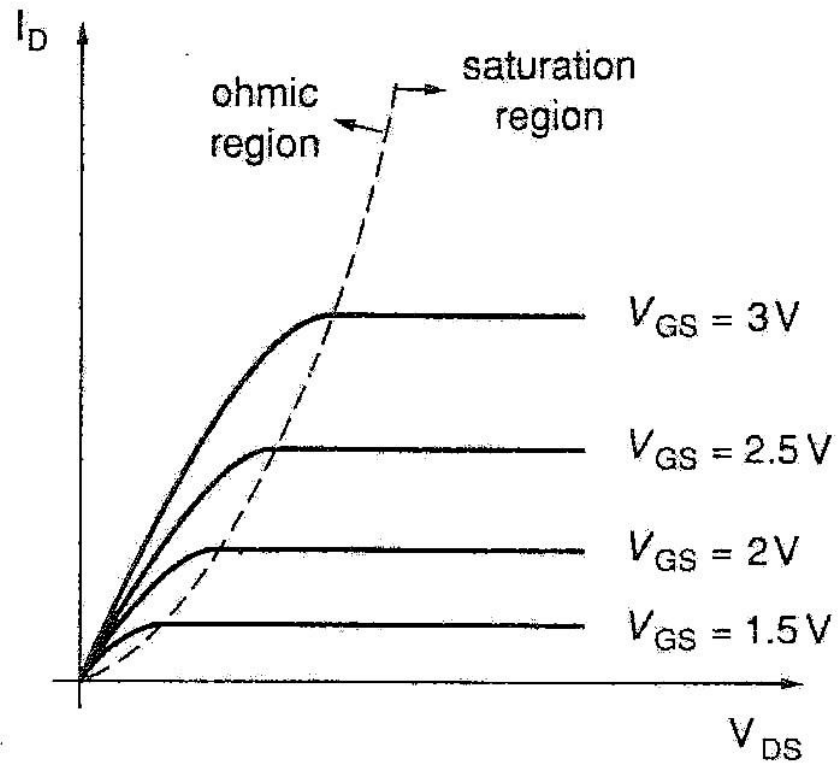
$$I_D = K \left[ (V_{GS} - V_T) - \frac{V_{DS}}{2} \right] V_{DS}$$

# II. Regiunea de inversie slaba

$$V_{GS} < V_T$$

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

# Caracteristicile de iesire ale tranzistorului MOS



## Efectele de ordin secundar:

### a. Modularea lungimii canalului

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

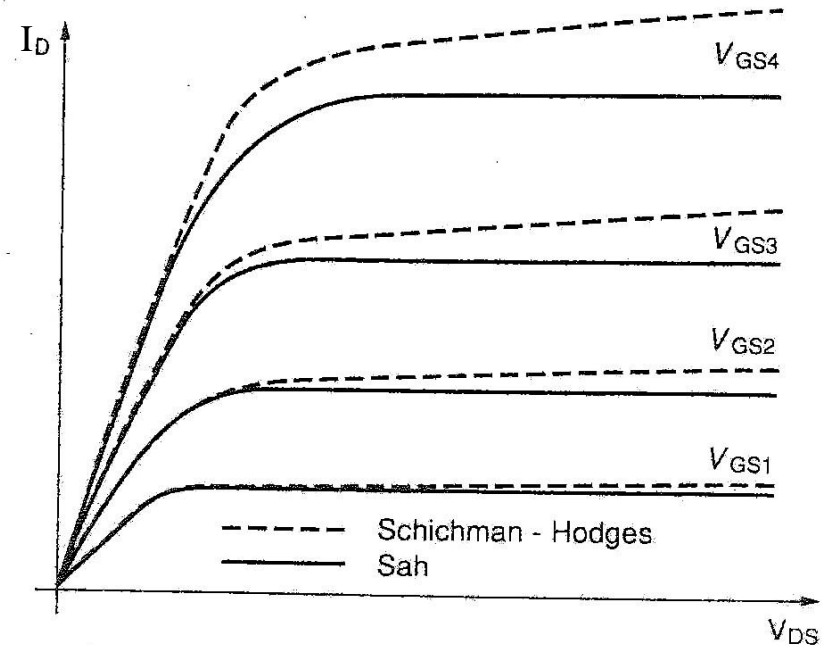
### b. Degradarea mobilitatii

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

### c. Efectul de substrat

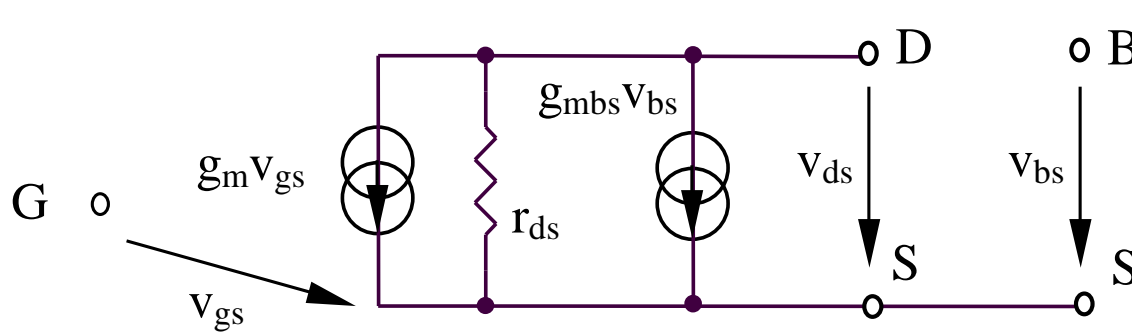
$$V_T = V_{T0} + \gamma (\sqrt{\Phi} - V_{BS} - \sqrt{\Phi})$$

## Modularea lungimii canalului





## 1.1.2. Modelul de semnal mic al tranzistorului MOS



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

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

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

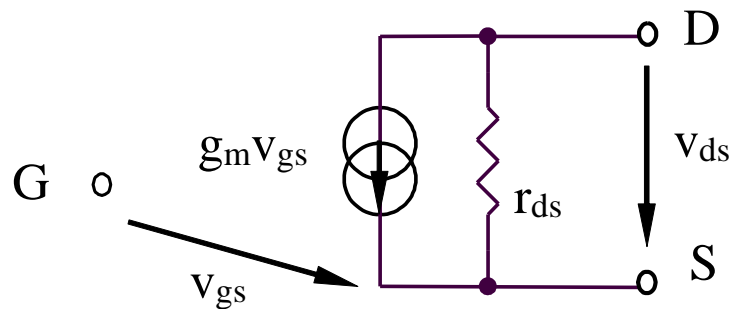
$$I_D = \frac{K}{2}(V_{GS} - V_T)^2 \Rightarrow V_{GS} - V_T = \sqrt{\frac{2I_D}{K}}$$

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

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

## 1.1.2. Modelul de semnal mic al tranzistorului MOS

( $V_{bs} = 0$ )



$$r_{ds} \cong \frac{1}{\lambda I_D}$$

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

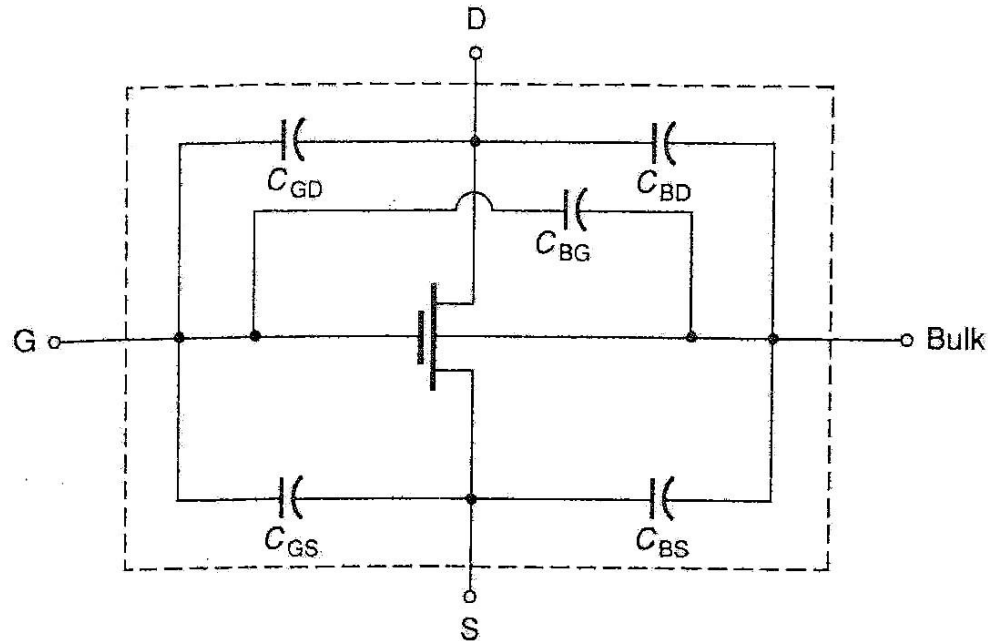
## Exemplu

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

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

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

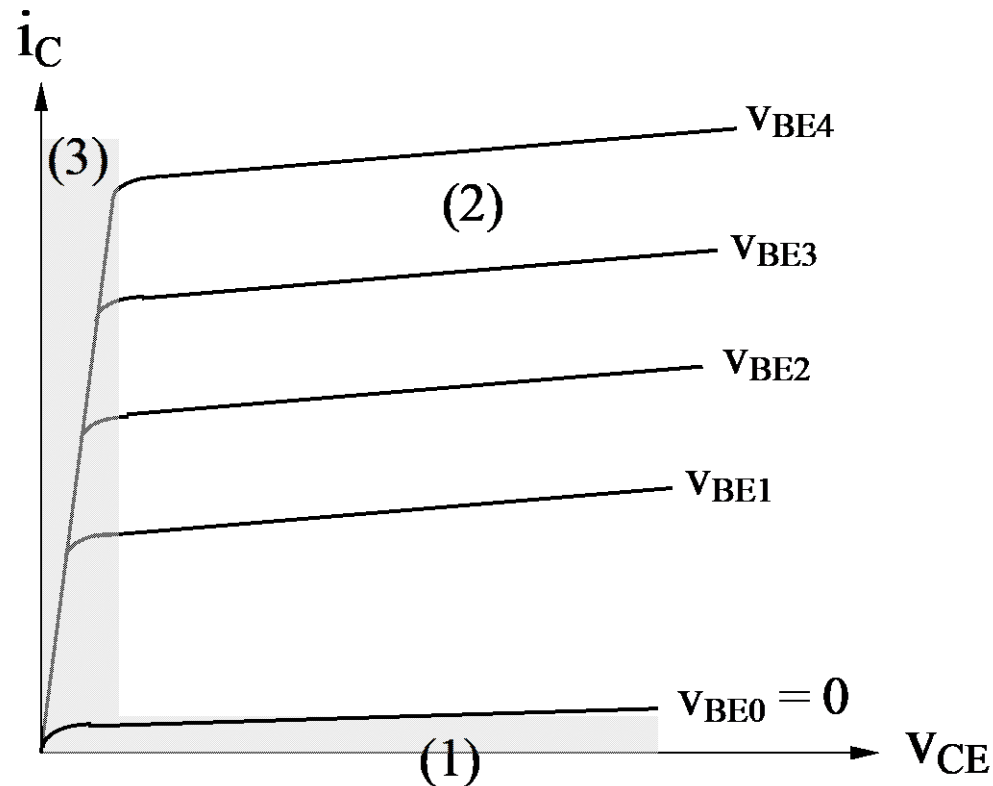
## Modelul de inalta frecventa



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

Domenii de functionare:

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



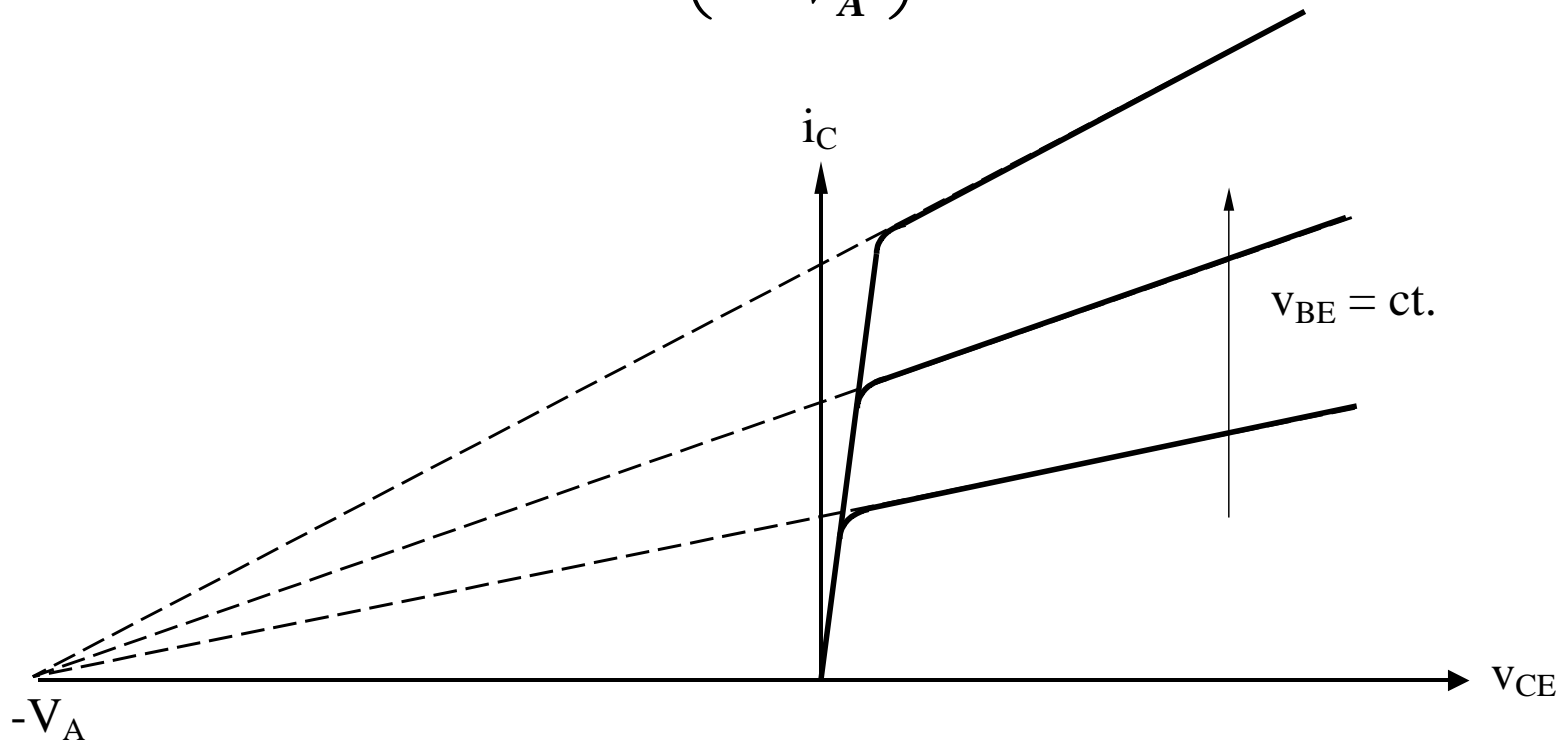
## 1.2.1. Functionarea la semnal mare

Regim activ normal:

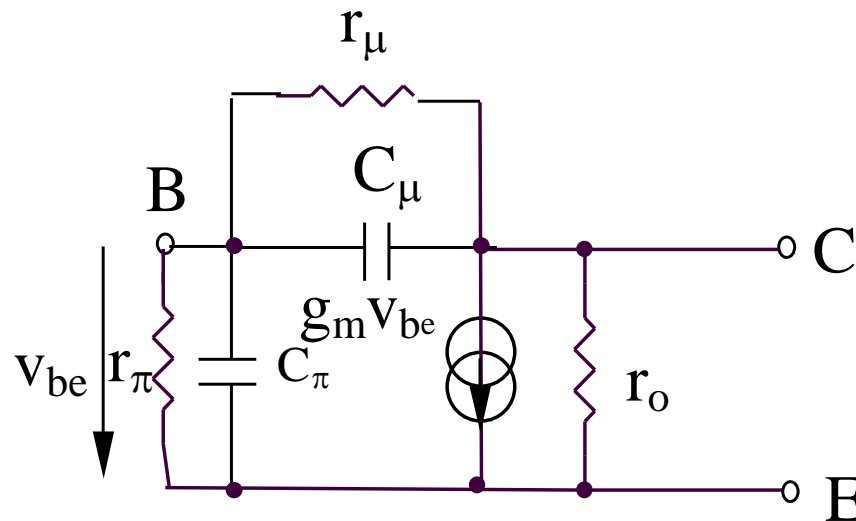
$$i_c = I_S \left( e^{\frac{v_{BE}}{V_{th}}} - 1 \right) \cong I_S e^{\frac{v_{BE}}{V_{th}}}$$

Efectul Early:

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



## 1.2.2. 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:

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

Rezistenta  $r_\pi$ :

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

Rezistenta  $r_\mu$ :

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

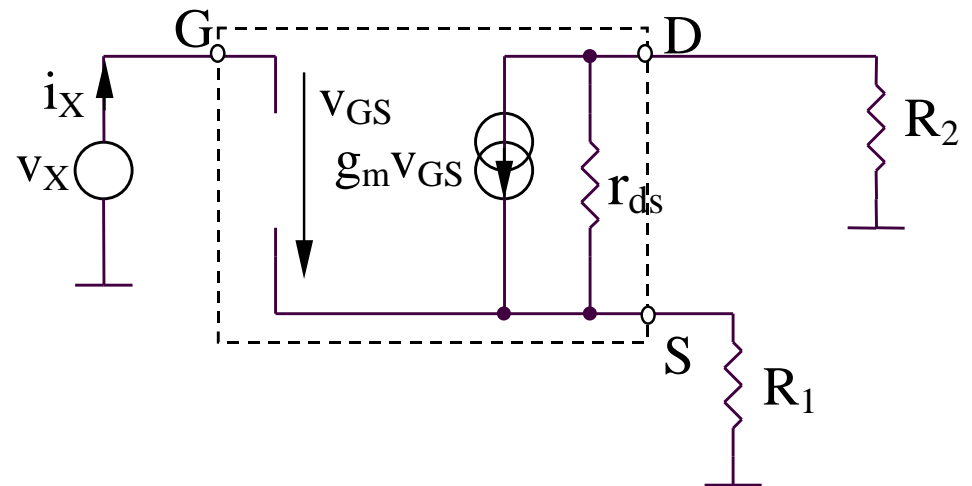
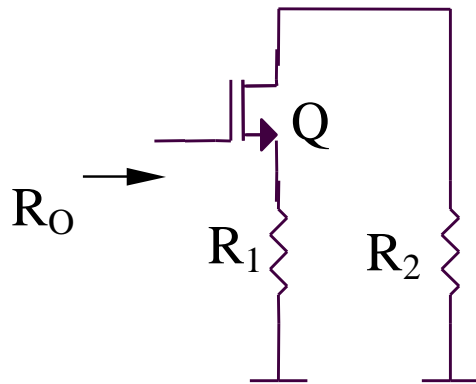
**$K \geq 10$  pt. NPN**

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



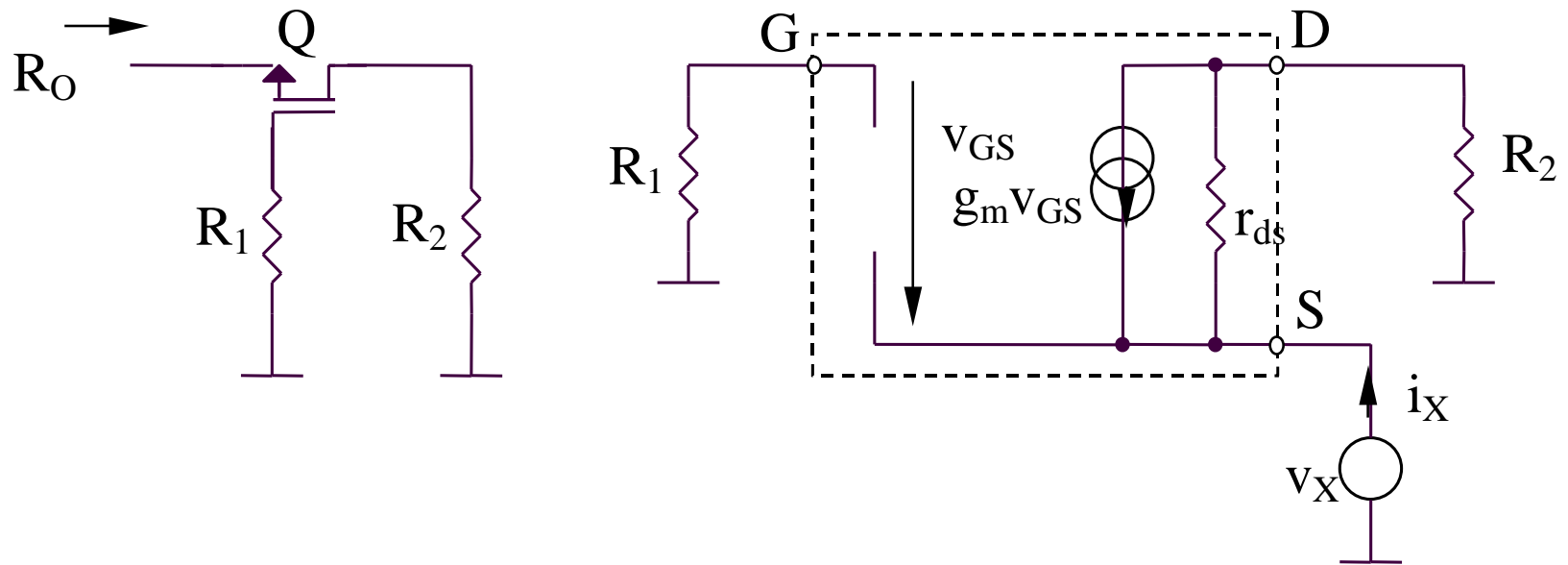
## **1.3. Rezistente dinamiche**

## Rezistența în poarta



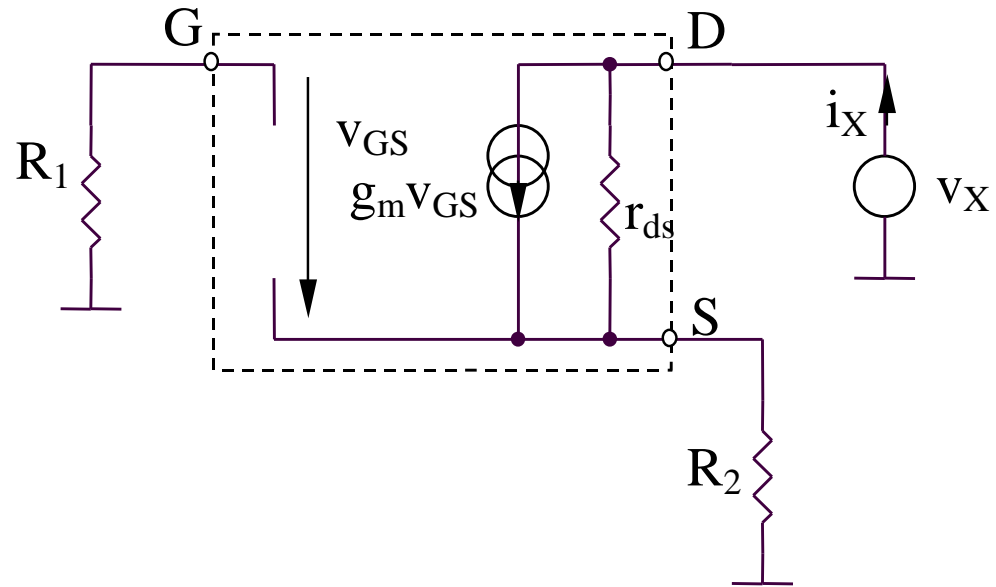
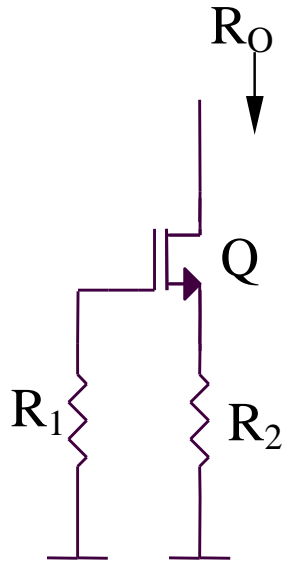
$$R_O = \infty$$

## Rezistența în sursă



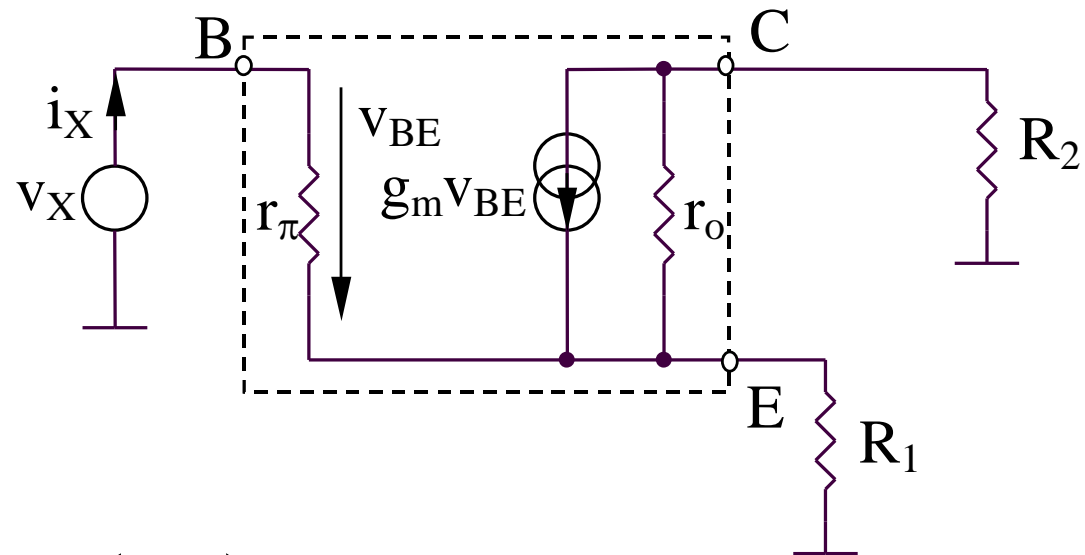
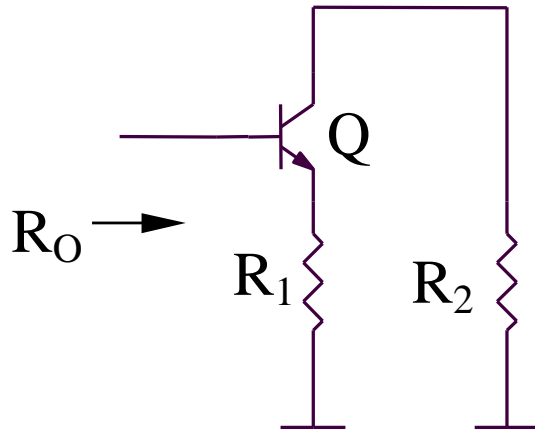
$$i_x \cong -g_m v_{gs} = g_m v_x \Rightarrow R_O = \frac{v_x}{i_x} = \frac{1}{g_m}$$

## Rezistenta in drena



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

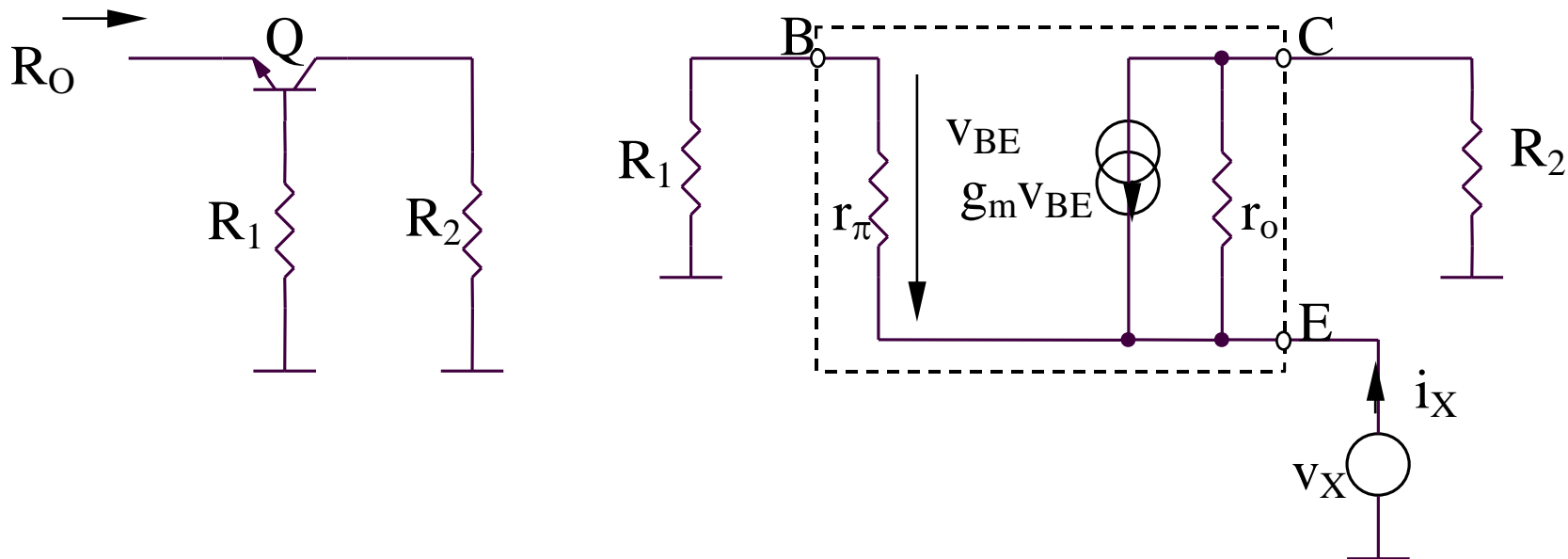
## Rezistenta in baza



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

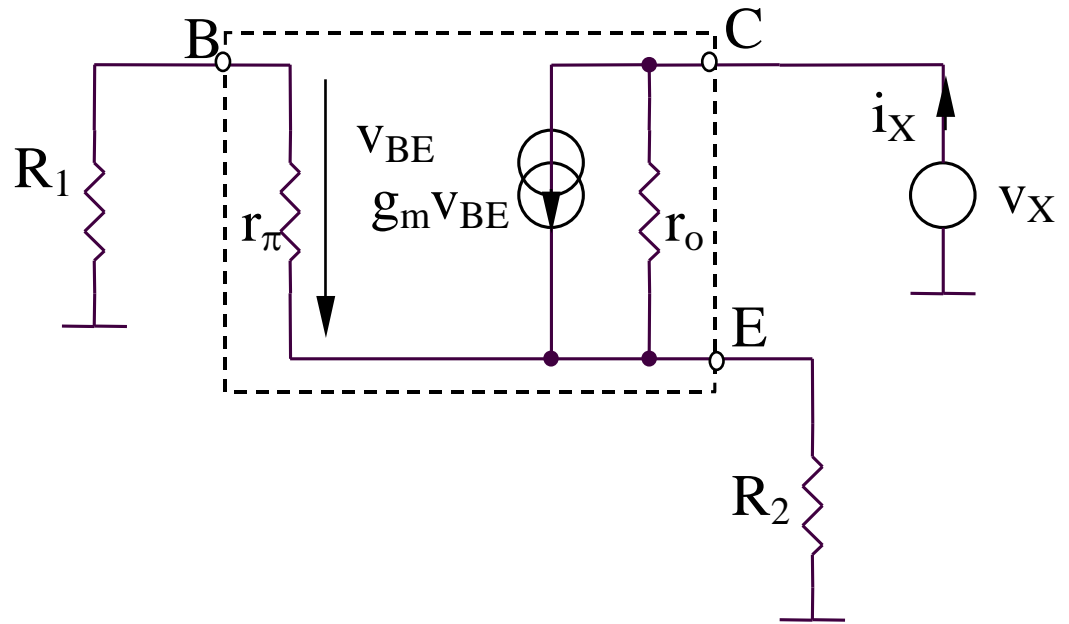
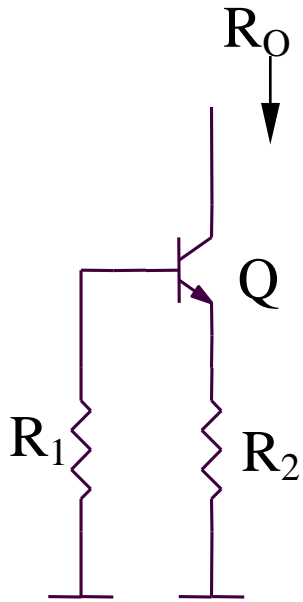
$$R_O = \frac{v_x}{i_x} = r_\pi + (\beta + 1) R_1$$

## Rezistența în emitor



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

## Rezistența în colector



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