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
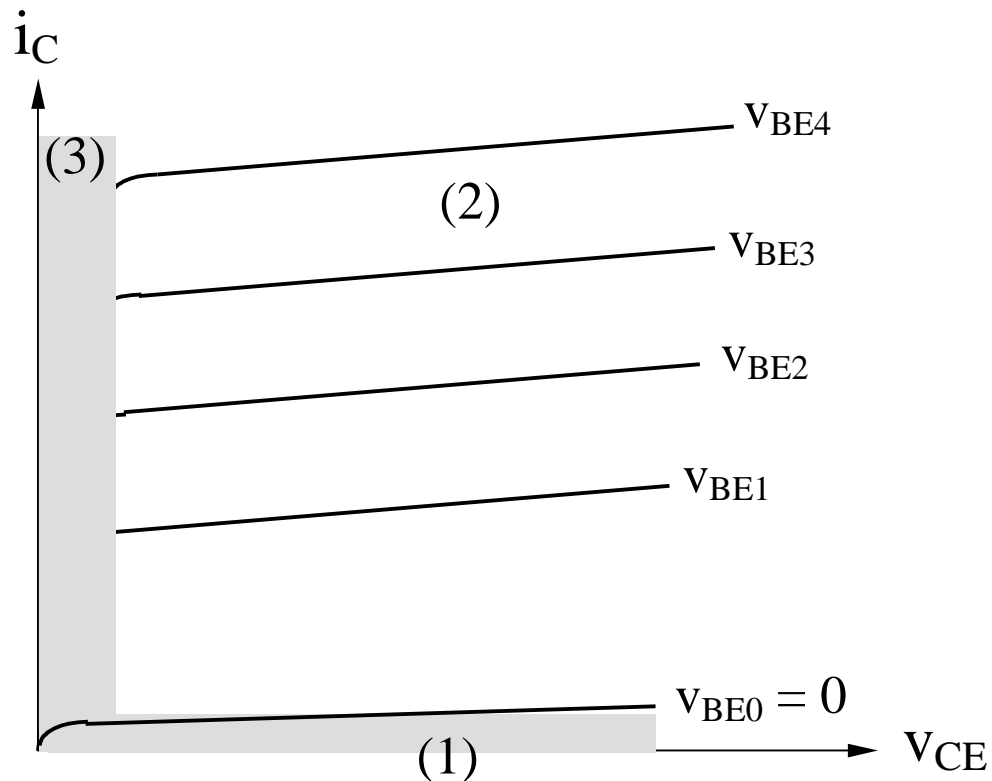9. Structuri neliniare de calcul analogic

Capitolul 1

Modelarea dispozitivelor bipolare si MOS

1.1. Relatii fundamentale ale tranzistorului bipolar

Domenii de functionare:

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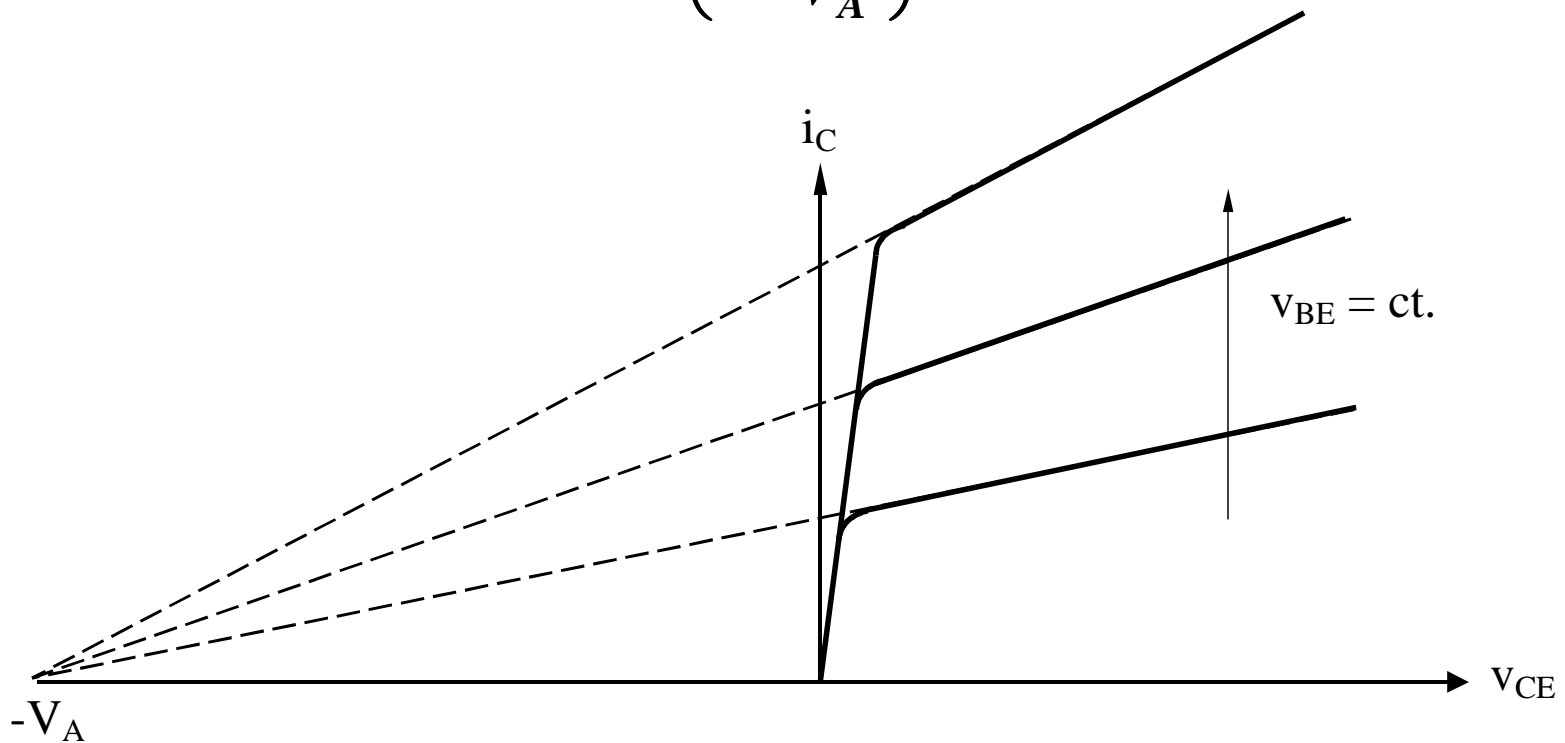- Regiunea activa normala (2)
- Regiunea de saturatie (3)

i_C

(3)

v_{BE4}

(2)

v_{BE3}

v_{BE2}

v_{BE1}

$v_{BE0} = 0$

(1)

v_{CE}

1.1.1. Functionarea la semnal mare
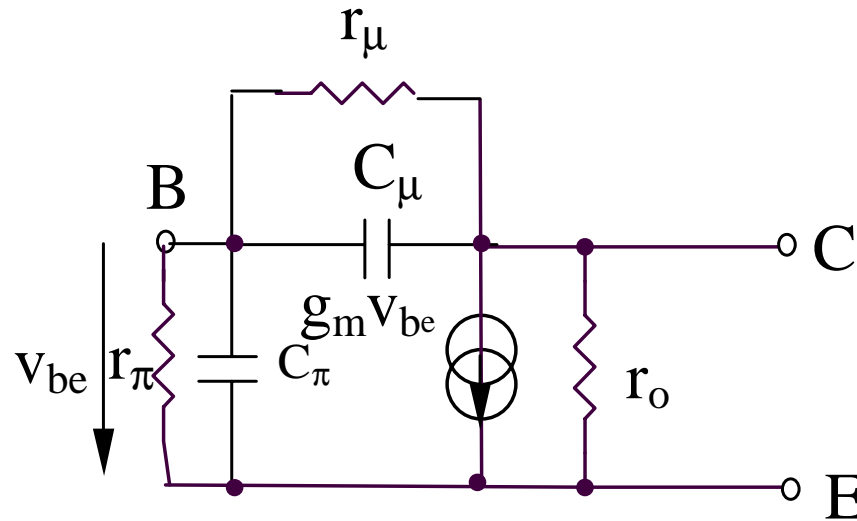
Regim activ normal:

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

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:

$$\left. \begin{array}{c} g_m = \dfrac{\partial I_C}{\partial V_{BE}} \\[3em] I_C \cong I_S \exp\left(\dfrac{V_{BE}}{V_{th}}\right) \end{array} \right\} \Rightarrow g_m = I_S \exp\left(\dfrac{V_{BE}}{V_{th}}\right)\dfrac{1}{V_{th}} = \dfrac{I_C}{V_{th}} \cong 40 I_C$$

Rezistenta de iesire:

$$r_o = \frac{1}{g_o} = \frac{1}{\dfrac{\partial I_C}{\partial V_{CE}}}$$

$$I_C = I_S \exp\left(\frac{V_{BE}}{V_{th}}\right)\left(1 + \frac{V_{CE}}{V_A}\right)$$

$$\Rightarrow r_o = \frac{1}{I_S \exp\left(\dfrac{V_{BE}}{V_{th}}\right)\dfrac{1}{V_A}} \cong \frac{V_A}{I_C}$$

Rezistenta r_π:

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

Rezistenta r_μ:

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

$$K \geq 10 \ pt.NPN$$
$$K = 2 - 5 \ pt.PNP$$
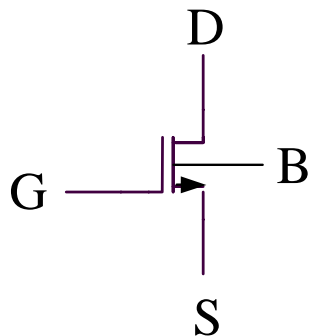
Circuit echivalent cu rezistente serie

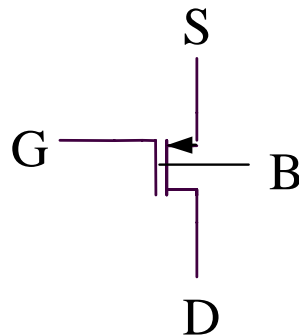# 1.2. Relatii fundamentale ale tranzistorului MOS

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

$$V_{GS} < V_T$$

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

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

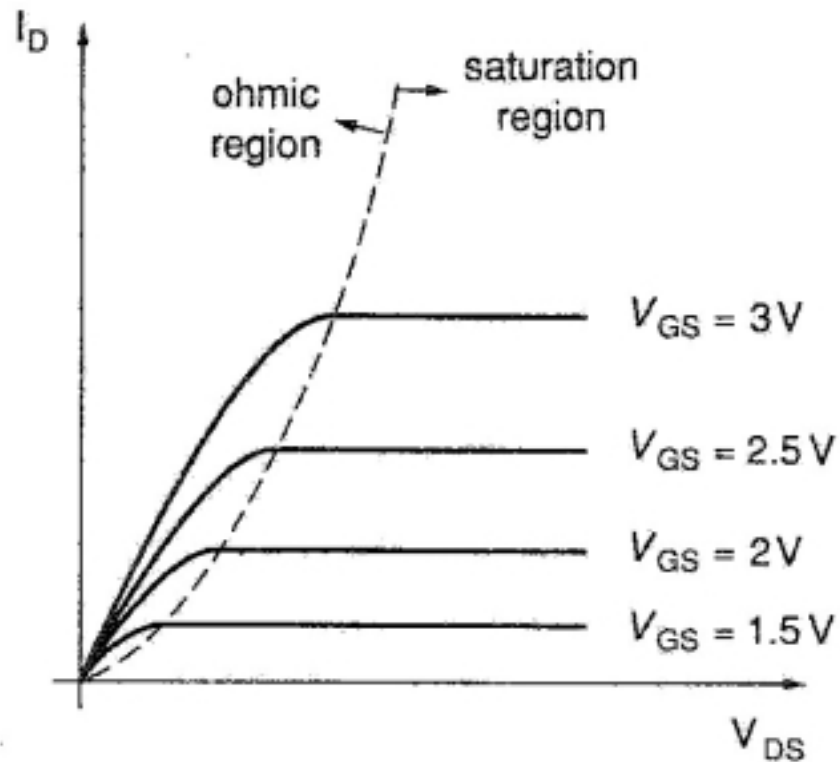$$\frac{\partial I_D}{\partial V_{GS}}\bigg|_{sat} = \frac{\partial I_D}{\partial V_{GS}}\bigg|_{w.i.}$$

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

$$\Rightarrow \begin{cases} \dfrac{V_{GS} - V_T}{2} = nV_{th} \\[3mm] \dfrac{K}{2}(2nV_{th})^2 = I_{D0}\dfrac{W}{L}e^2 \end{cases}$$

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

$$\Rightarrow \begin{cases} V_{GS} = V_T + nV_{th} \\[3mm] I_{D0} = \dfrac{K'2(nV_{th})^2}{e^2} \end{cases}$$

Caracteristicile de iesire ale tranzistorului MOS

Efectele de ordin secundar:

a. Modularea lungimii canalului

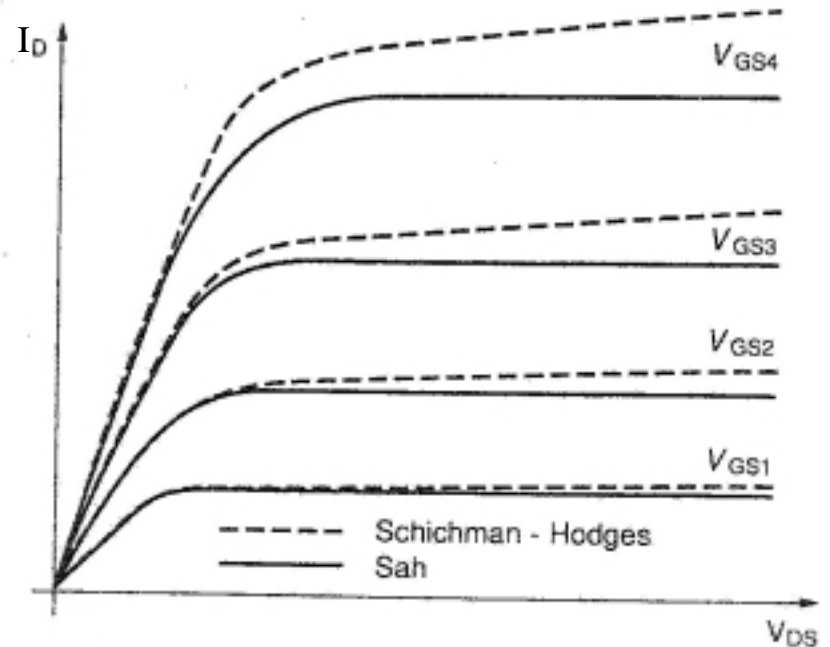$$I_D = \frac{K}{2}(V_{GS} - V_T)^2 (1 + \lambda V_{DS})$$

b. Degradarea mobilitatii

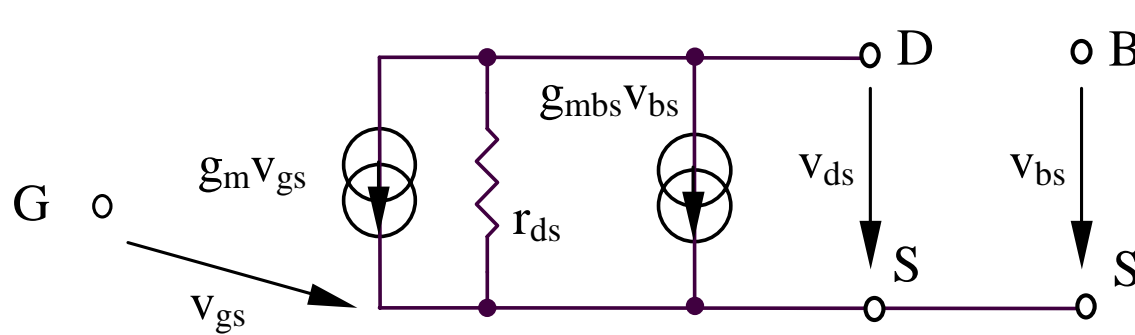$$K = \frac{K_0}{[1 + \theta_G (V_{GS} - V_T)](1 + \theta_D V_{DS})}$$

c. Efectul de substrat

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

Modularea lungimii canalului

1.2.2. Modelul de semnal mic al tranzistorului MOS

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

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

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

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

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

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

Exemplu

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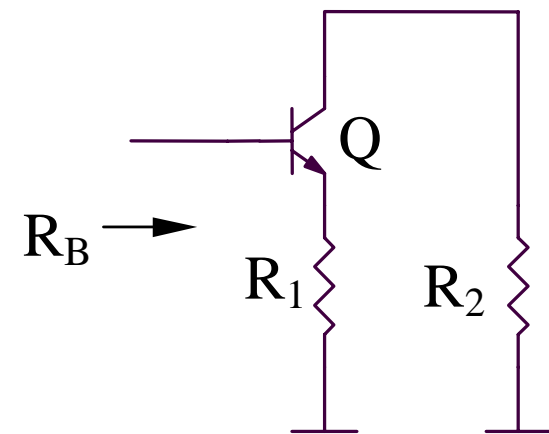
$$\Rightarrow g_m = \sqrt{2KI_D} = 1mA/V$$

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

Modelul de inalta frecventa
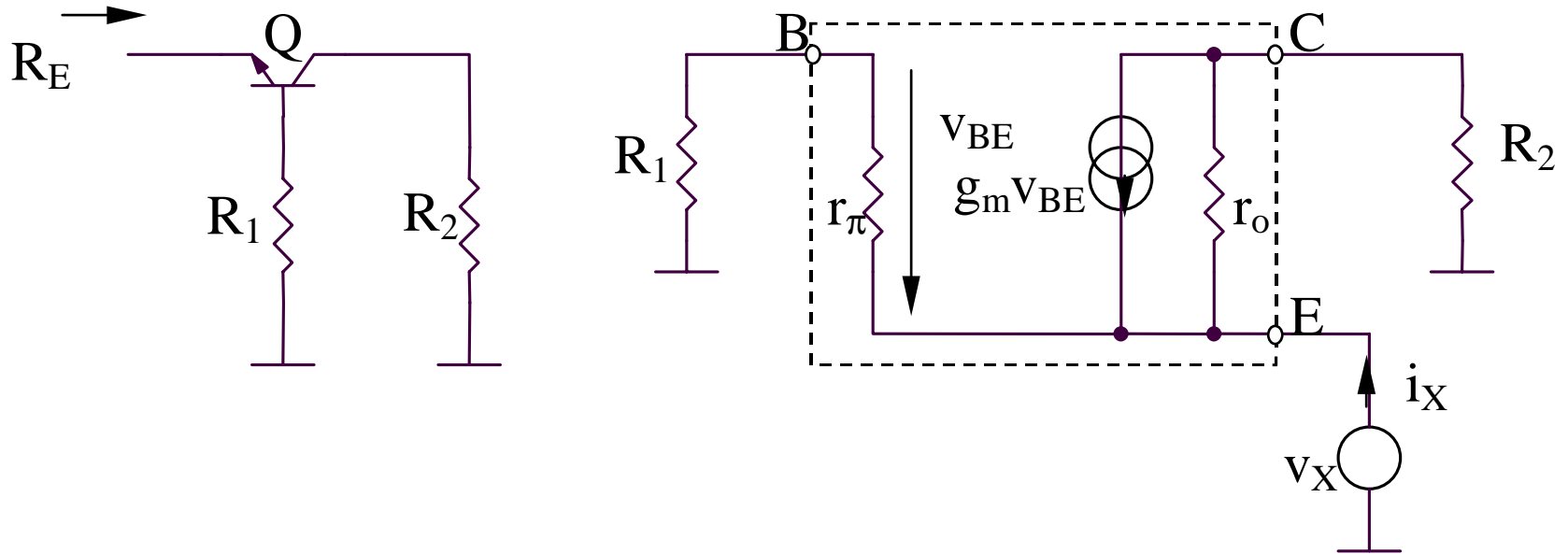
1.3. Rezistente dinamice

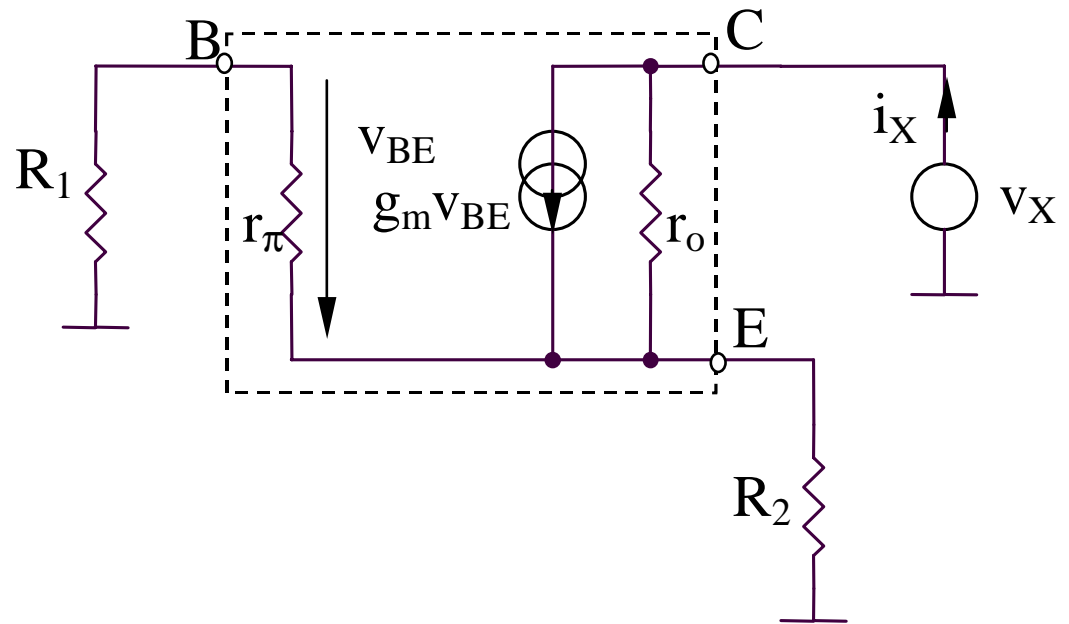# Rezistenta in baza

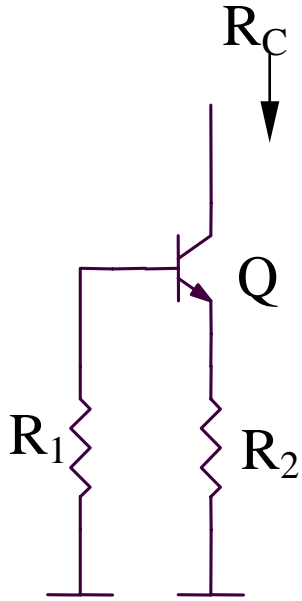
$$v_x = i_x r_\pi + (\beta + 1) i_x R_1$$

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

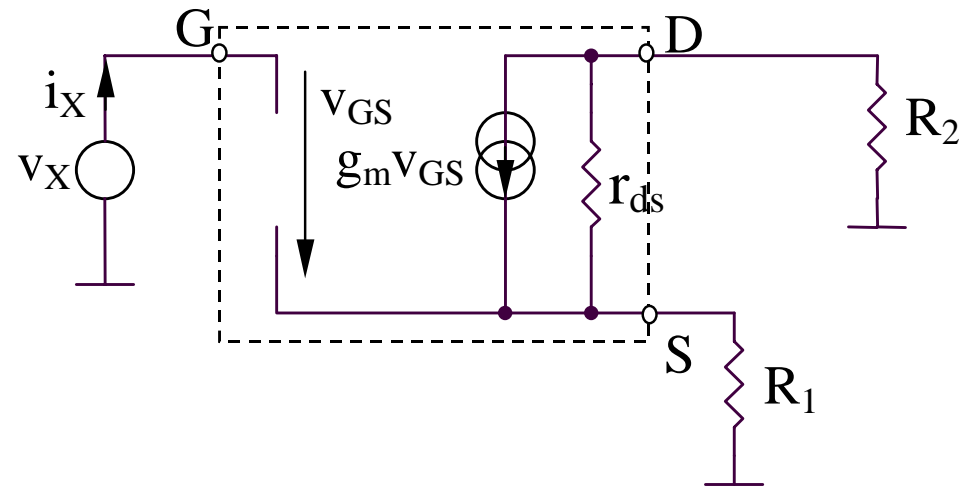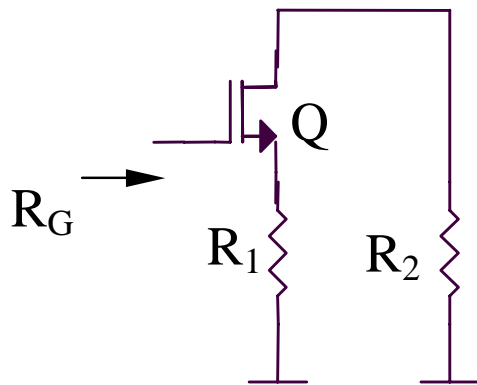# Rezistenta in emitor

$$R_E = \frac{R_1 + r_\pi}{\beta + 1}$$
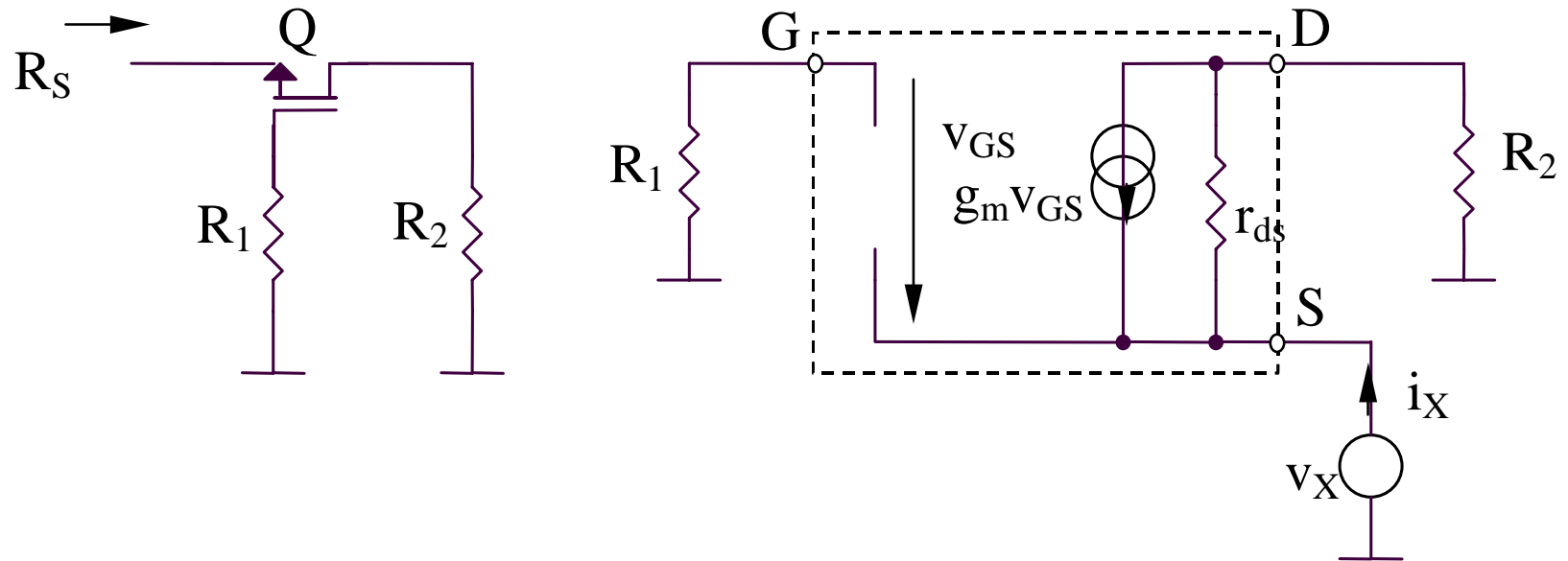
Rezistenta in colector

$$R_C = r_o \left(1 + \frac{\beta R_2}{r_\pi + R_1 + R_2} \right)$$
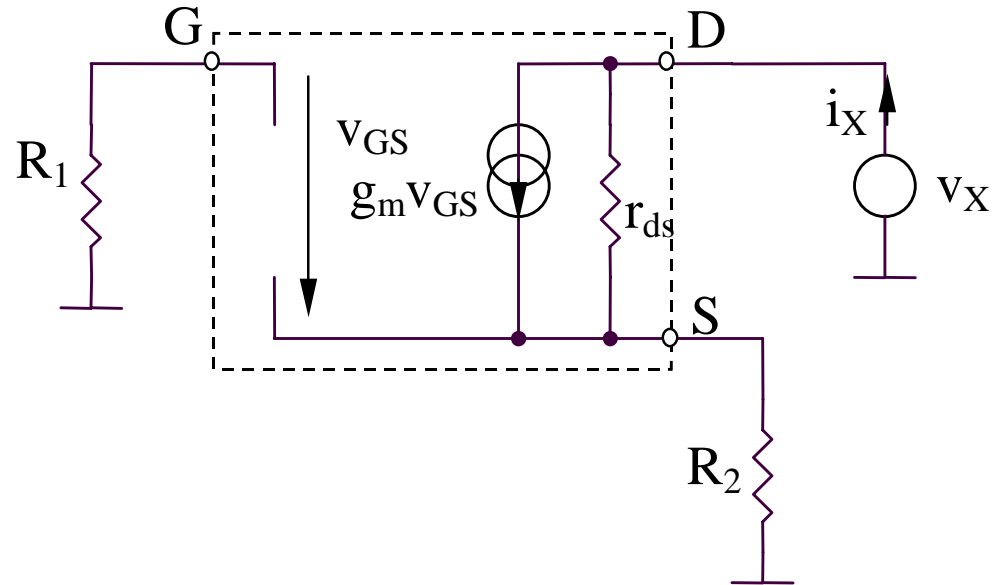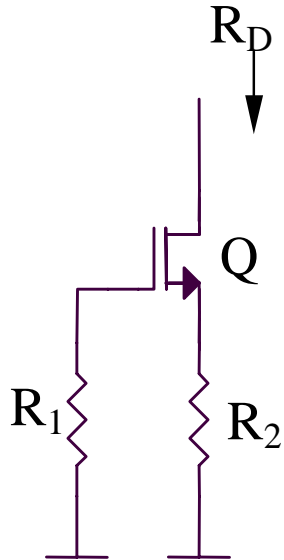
Rezistenta in poarta

$$R_G = \infty$$

Rezistenta in sursa

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

Rezistenta in drena

$$v_x = (i_x - g_m v_{gs})r_{ds} + i_x R_2$$
$$v_{gs} = -i_x R_2$$

$$\Rightarrow R_D = \frac{v_x}{i_x} = r_{ds}(1 + g_m R_2) + R_2 \cong r_{ds}(1 + g_m R_2)$$