Fakultet elektrotehnike i računarstva
Zavod za elektroniku, mikroelektroniku,
računalne i inteligentne sustave

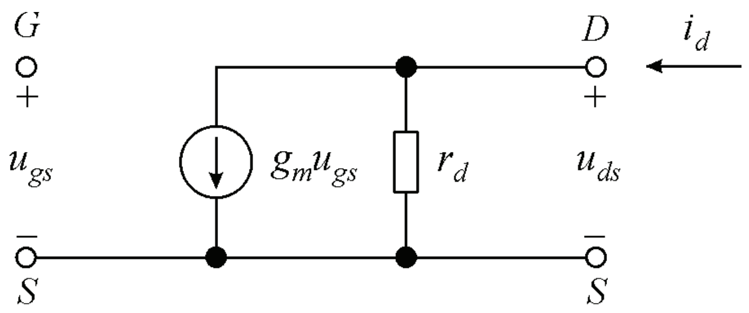
Elektronika 2

Modeli tranzistora za mali signal

Model FET-a za mali signal

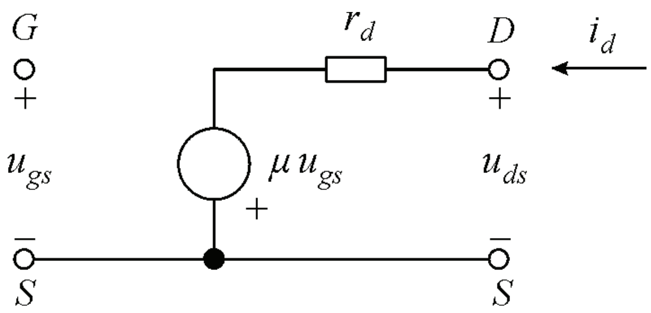
Koristi se u području zasićenja

Slijedi iz: $i_d = g_m u_{gs} + u_{ds}/r_d$



Drugi oblik

$u_{ds} = -\mu u_{gs} + r_d i_d, \ \mu = g_m r_d$



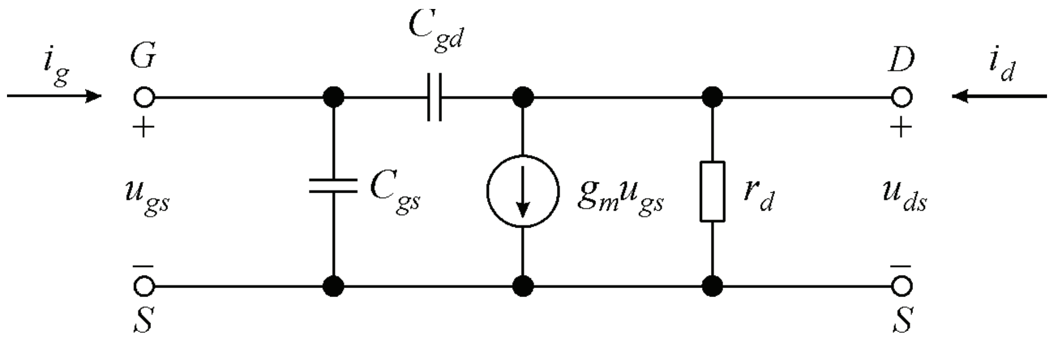
faktor naponskog pojačanja

$$\mu = -\left.\frac{\mathrm{d}u_{DS}}{\mathrm{d}u_{GS}}\right|_{I_D = \text{konst}} = -\left.\frac{u_{ds}}{u_{gs}}\right|_{u_{ds}=0}$$

Za neopterećen izlaz $\rightarrow i_d = 0$ $\quad u_{ds} = -g_m r_d u_{gs} = -\mu u_{gs}$

maksimalno naponsko pojačanje FET- a

Model za visoke frekvencije



Kapaciteti C_{gs} i C_{gd}:

za MOSFET → kapacitet MOS strukture

za JFET → kapacitet zaporno polariziranih *pn*-spojeva

za MESFET → kapacitet zaporno polariziranog spoja metal-poluvodič

Analitičko određivanje dinamičkih parametara (1)

Strmina:

- MOSFET

$$i_D = \frac{K}{2}\left(u_{GS} - U_{GS0}\right)^2$$

$$g_m = \frac{\mathrm{d}\, i_D}{\mathrm{d}\, u_{GS}} = K\left(U_{GS} - U_{GS0}\right) = \sqrt{2\, K\, I_D}$$

- JFET

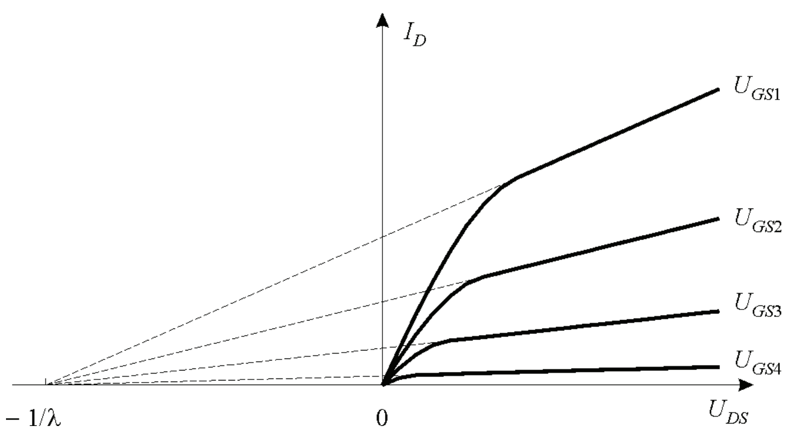
$$i_D = I_{DSS}\left(1 - \frac{u_{GS}}{U_P}\right)^2$$

$$g_m = \frac{\mathrm{d}\, i_D}{\mathrm{d}\, u_{GS}} = \frac{2\, I_{DSS}}{-U_P}\left(1 - \frac{U_{GS}}{U_P}\right) = \frac{2}{-U_P}\sqrt{I_{DSS}\, I_D}$$

Analitičko određivanje dinamičkih parametara (2)

Izlazni dinamički otpor:

model nagiba izlaznih karakteristika u području zasićenja



$$r_d = \frac{1}{g_d} \approx \frac{1}{\lambda I_D}$$

- MOSFET

$$i_D = \frac{K}{2}\left(u_{GS} - U_{GS0}\right)^2\left(1 + \lambda u_{DS}\right)$$

$$g_d = \frac{\mathrm{d}i_D}{\mathrm{d}u_{DS}} = \lambda \frac{K}{2}\left(U_{GS} - U_{GS0}\right)^2 \approx \lambda I_D$$

- JFET

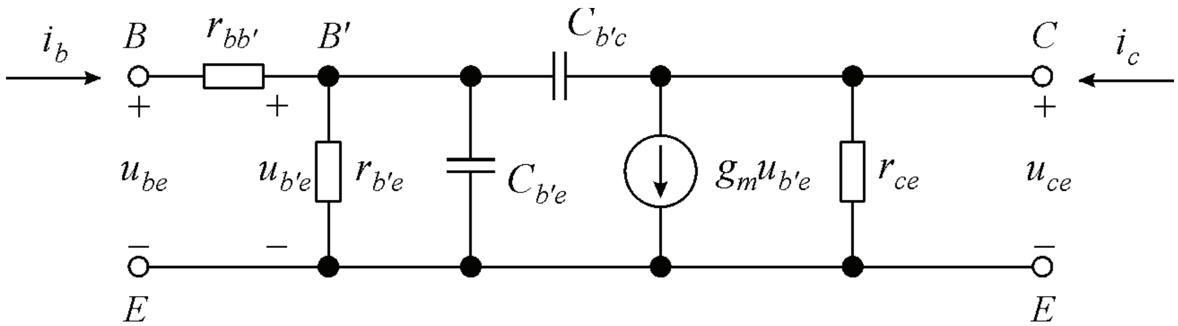
$$i_D = I_{DSS}\left(1 - \frac{u_{GS}}{U_P}\right)^2\left(1 + \lambda u_{DS}\right)$$

$$g_d = \frac{\mathrm{d}i_D}{\mathrm{d}u_{DS}} = \lambda I_{DSS}\left(1 - \frac{U_{GS}}{U_P}\right)^2 \approx \lambda I_D$$

Hibridni π-model bipolarnog tranzistora

Visokofrekvencijski hibridni π-model

Koristi se u normalnom aktivnom području

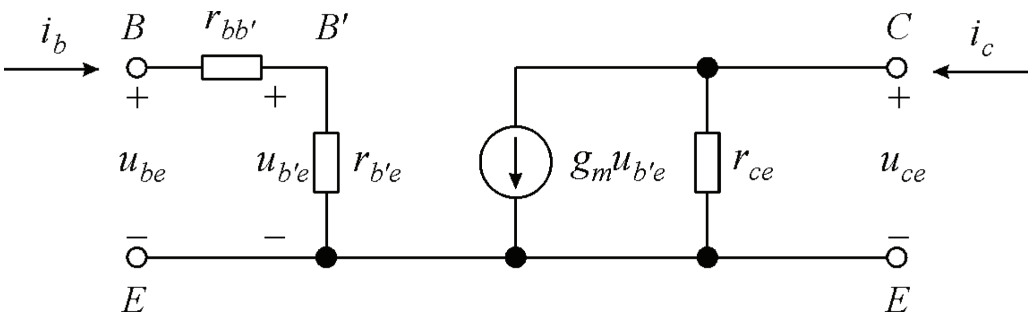


Kapaciteti:

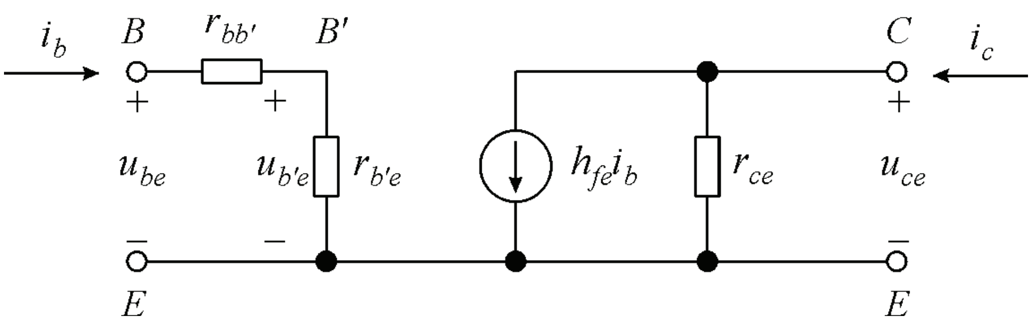
$C_{b'e}$ → kapacitet spoja emiter-baza; difuzijski kapacitet

$C_{b'c}$ → kapacitet spoja kolektor-baza; kapacitet osiromašenog sloja

Niskofrekvencijski modeli bipolarnog tranzistora



Model sa strminom g_m

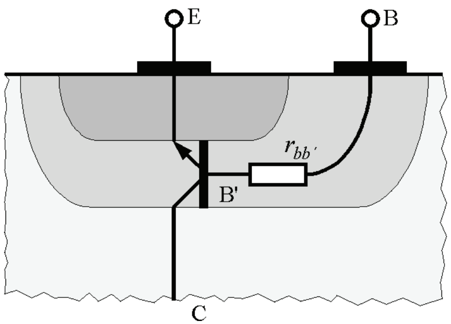


Model s faktorom strujnog pojačanja h_{fe}

Ulazni dinamički otpor bipolarnog tranzistora

ukupni otpor $r_{be} \rightarrow r_{be} = r_{bb'} + r_{b'e}$

- serijski otpor baze $r_{bb'} \rightarrow$



- dinamički otpor spoja emiter-baza $r_{b'e}$

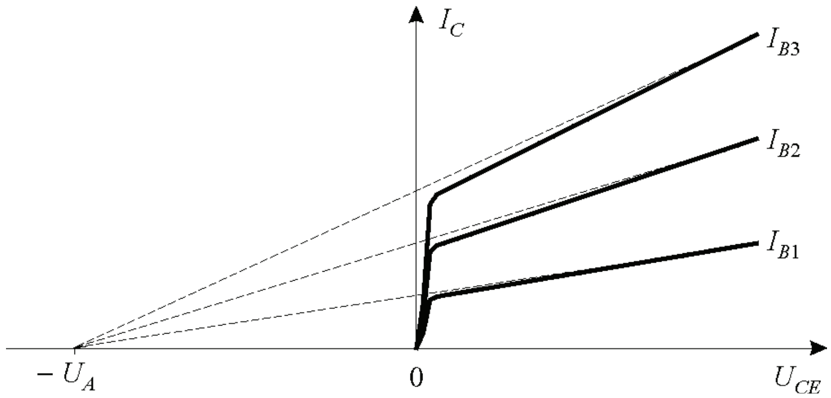
$$i_B = i_{PE} + i_R = q\,S\,D_{pE}\frac{p_{0E}}{L_{pE}}\exp\left(\frac{u_{B'E}}{U_T}\right) + q\,S\,\frac{w_B\,n_{0B}}{2\,\tau_{nB}}\exp\left(\frac{u_{B'E}}{U_T}\right)$$

$$\frac{1}{r_{b'e}} = \frac{di_B}{du_{B'E}} = \frac{i_B}{U_T}$$

u radnoj točki: $$r_{b'e} = \frac{U_T}{I_B}$$

Izlazni dinamički otpor bipolarnog tranzistora

model nagiba izlaznih karakteristika u
području zasićenja



$$i_C = \beta i_B \left(1 + \frac{u_{CE}}{U_A}\right)$$

$$\frac{1}{r_{ce}} = \frac{di_C}{du_{CE}} = \frac{i_C}{u_{CE} + U_A}$$

$$r_{ce} = \frac{U_{CE} + U_A}{I_C} \approx \frac{U_A}{I_C}$$

$U_A \equiv$ Earlyjev napon

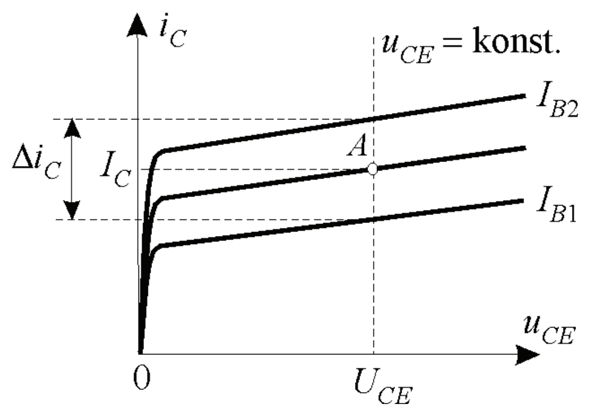
Dinamički faktor strujnog pojačanja u spoju zajedničkog emitera

opisuje pojačanje tranzistora

$$h_{fe} = \left.\frac{\mathrm{d}i_C}{\mathrm{d}i_B}\right|_{u_{CE}=\mathrm{konst}} = \left.\frac{i_c}{i_b}\right|_{u_{ce}=0}$$

$$h_{fe} \approx \beta$$

očitavanje iz izlaznih karakteristika



$$h_{fe} = \left.\frac{\Delta i_C}{\Delta i_B}\right|_{u_{CE}=\mathrm{konst}} = \left.\frac{\Delta i_C}{I_{B2} - I_{B1}}\right|_{u_{CE}=\mathrm{konst}}$$

Strmina bipolarnog tranzistora

drugi parametar koji opisuje pojačanje tranzistora

$$g_m = \left.\frac{\mathrm{d}i_C}{\mathrm{d}u_{B'E}}\right|_{u_{CE} = \mathrm{konst}} = \left.\frac{i_c}{u_{b'e}}\right|_{u_{ce} = 0}$$

$$g_m = \frac{\mathrm{d}i_C}{\mathrm{d}u_{B'E}} = \frac{\mathrm{d}i_C}{\mathrm{d}i_B}\frac{\mathrm{d}i_B}{\mathrm{d}u_{B'E}} = \frac{h_{fe}}{r_{b'e}}$$

u radnoj točki: $$g_m \approx \frac{\beta}{U_T / I_B} = \frac{I_C}{U_T}$$