

**Četveropoli:**

$$\underline{y}_{mn} = g_{mn} + j b_{mn} \quad \underline{z}_{mn} = r_{mn} + j x_{mn} \quad I_1 = \underline{y}_{11} U_1 + \underline{y}_{12} U_2 \quad U_1 = \underline{z}_{11} I_1 + \underline{z}_{12} I_2 \quad U_1 = \underline{h}_{11} I_1 + \underline{h}_{12} U_2$$

$$\underline{h}_{mn} = \text{Re}[\underline{h}_{mn}] + j \text{Im}[\underline{h}_{mn}] \quad I_2 = \underline{y}_{21} U_1 + \underline{y}_{22} U_2 \quad U_2 = \underline{z}_{21} I_1 + \underline{z}_{22} I_2 \quad I_2 = \underline{h}_{21} I_1 + \underline{h}_{22} U_2$$

**Polprevodnik:**

$$n = N_C e^{-\frac{E_C - E_F}{kT}} = n_i e^{\frac{E_F - E_{Fi}}{qU_T}} = n_i e^{\frac{V_{Fi} - V_F}{U_T}} \quad J_n = q \mu_n n E + q D_n \frac{dn}{dx} \quad \frac{\partial n}{\partial t} = -\frac{n - n_0}{\tau_n} + \frac{1}{q} \frac{\partial j_n}{\partial x} \quad \rho = q(p - n + N_D - N_A) \quad L = \sqrt{D\tau}$$

$$p = N_V e^{-\frac{E_F - E_V}{kT}} = n_i e^{\frac{E_F - E_{Fp}}{qU_T}} = n_i e^{\frac{V_{Fp} - V_F}{U_T}} \quad J_p = q \mu_p p E - q D_p \frac{dp}{dx} \quad \frac{\partial p}{\partial t} = -\frac{p - p_0}{\tau_p} - \frac{1}{q} \frac{\partial j_p}{\partial x} \quad -\frac{d^2 V}{dx^2} = \frac{dE}{dx} = \frac{\rho}{\epsilon} \quad \frac{D}{\mu} = \frac{kT}{q} = U_T$$

**pn dioda:**

$$I = A J = A q \left( \frac{D_p p_{n0}}{L_p} + \frac{D_n n_{p0}}{L_n} \right) \left( e^{\frac{U}{U_T}} - 1 \right) = A q n_i^2 \left( \frac{D_p}{L_p N_D} + \frac{D_n}{L_n N_A} \right) \left( e^{\frac{U}{U_T}} - 1 \right) = I_S \left( e^{\frac{U}{U_T}} - 1 \right)$$

$$U_D = V_{Fim} - V_{Fip} = U_T \ln \frac{p_{p0}}{p_{n0}} = U_T \ln \frac{n_{n0}}{n_{p0}} = U_{Fp} + U_{Fn} = U_T \ln \frac{p_{p0} n_{n0}}{n_i^2} \cong$$

$$\cong U_T \ln \frac{N_A N_D}{n_i^2} = U_p + U_n = \frac{q}{2\epsilon} (N_A x_p^2 + N_D x_n^2)$$

$$x_n = \sqrt{\frac{2\epsilon N_A (U_D + U_R)}{q N_D (N_A + N_D)}} \quad D = x_p + x_n = \sqrt{\frac{2\epsilon \left( \frac{1}{N_A} + \frac{1}{N_D} \right) (U_D + U_R)}{q}}$$

$$x_p = \sqrt{\frac{2\epsilon N_D (U_D + U_R)}{q N_A (N_A + N_D)}}$$

**Malosignalni model pn diode:**

$$C_T = \frac{\epsilon A}{D}$$

$N_A \square N_D$  &  $u = U_F$ :

$$\underline{y} = \frac{I}{U} = \frac{I}{U_T} \sqrt{1 + j\omega\tau_p} = g + jb$$

$$g|_{NF} = \frac{I}{U_T} \quad C_d|_{NF} = \frac{g|_{NF} \tau_p}{2}$$

$$g|_{VF} = g|_{NF} \sqrt{\frac{\omega\tau_p}{2}} \quad C_d|_{VF} = \frac{g|_{VF}}{\omega}$$

**Ebers-Mollov model bipolarnega tranzistorja (pnp):**

$$I_E = I_F - \alpha_R I_R \quad I_F = I_{ES} \left( e^{\frac{U_{EB}}{U_T}} - 1 \right) \quad I_E = I_{E0} \left( e^{\frac{U_{EB}}{U_T}} - 1 \right) - \alpha_R I_C$$

$$I_C = -\alpha_F I_F + I_R \quad I_R = I_{CS} \left( e^{\frac{U_{CB}}{U_T}} - 1 \right) \quad I_C = -\alpha_F I_E + I_{C0} \left( e^{\frac{U_{CB}}{U_T}} - 1 \right)$$

$$I_{E0} = I_{ES} (1 - \alpha_F \alpha_R) \quad I_{C0} = I_{CS} (1 - \alpha_F \alpha_R) \quad \alpha_F I_{ES} = \alpha_R I_{CS}$$

**Malosignalni model bipolarnega tranzistorja:**

$$g_m = \alpha_0 g_e = \frac{I_C}{U_T} \quad g_e = \frac{I_E}{U_T} \quad r_{be} = \frac{\beta}{g_m}$$

$$A_i|_{U_{CB}=0} = -\frac{I_C}{I_E} \Big|_{U_{CB}=0} = \frac{\alpha_0}{1 + \frac{j\omega}{\omega_\alpha}} = \frac{\alpha_0}{1 + \frac{jf}{f_\alpha}} = \underline{\alpha}(f)$$

**Spojini FET (n kanal):**

$$I_{DS} = I_{DSS} \left( 1 - \frac{U_{GS}}{U_P} \right)^2 \quad U_P = U_D - \frac{qN_D D^2}{8\epsilon}$$

$$U_{DSSat} = U_{GS} - U_P$$

**MOS tranzistor (n kanal):**

$$I_D = \frac{C_0 W \mu_n}{L} \left[ (U_{GS} - U_T) U_{DS} - \frac{U_{DS}^2}{2} \right] \quad U_{DSSat} = U_{GS} - U_T$$

$$I_{DS} = \frac{C_0 W \mu_n U_T^2}{2L} \left( 1 - \frac{U_{GS}}{U_T} \right)^2$$

**Štirislojna dioda:**

$$I = \frac{M I_{C0}}{1 - M \alpha_1 - M \alpha_2}$$

**Tiristor:**

$$I = \frac{M I_{C0} + M \alpha_2 I_G}{1 - M \alpha_1 - M \alpha_2}$$

**Fotodioda:**

$$I = -I_S \left( e^{-\frac{U}{nU_T}} - 1 \right) + I_L$$

**Fototranzistor:**

$$-I_C = -I_B \frac{\alpha_F}{1 - \alpha_F} + \frac{I_{C0} + I_L}{1 - \alpha_F}$$

**Tabela fizikalnih konstant**

Boltzmannova konstanta	$k = 1.38 \times 10^{-23} \text{ J/K}$
absolutna vrednost naboja elektrona	$q = 1.6 \times 10^{-19} \text{ As}$
Planckova konstanta	$h = 6.625 \times 10^{-34} \text{ W s}^2$
masa elektrona	$m = 9.11 \times 10^{-31} \text{ kg}$
termična napetost	$U_T = kT/q = 25.66 \text{ mV} (T = 297.8 \text{ K} = 24.8 \text{ }^\circ\text{C})$
intrinzična koncentracija v Si	$n_i = 10^{10} \text{ cm}^{-3} (T = 297.8 \text{ K} = 24.8 \text{ }^\circ\text{C})$
dielektrična konstanta	$\epsilon_0 = 8.854 \times 10^{-12} \text{ As/(Vm)} = 8.854 \times 10^{-14} \text{ As/(Vcm)}$
relativna dielektrična konstanta Si	$\epsilon_r(\text{Si}) = 11.7 \quad \epsilon_0 \epsilon_{rSi} = 10^{-12} \text{ As/(Vcm)}$
relativna dielektrična konstanta SiO <sub>2</sub>	$\epsilon_r(\text{SiO}_2) = 3.85$