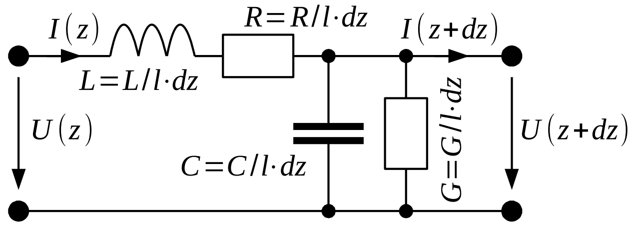
Smith-ov diagram

Obravnava elektrotehnične naloge je v časovnem prostoru povsem nazorna. Trenutne fizikalne veličine, na primer napetost $u(t)$ in tok $i(t)$, so natančno tisto, kar vidimo na zaslonu osciloskopa. Časovno odvisnost namenoma poudarimo z zapisom veličin z malimi črkami. Reševanje enačb tudi s povsem linearnimi gradniki žal v časovnem prostoru ni preprosto. Obnašanje gradnikov, ki lahko hranijo energijo, na primer tuljav L oziroma kondenzatorjev C, opisujejo odvodi oziroma integrali vpletenih veličin.

V resničnem prenosnem vodu moramo upoštevati tudi izgube. Kovinski vodniki dodajajo od nič različno zaporedno upornost R. Nebrezhibna izolacija dodaja vzporedno prevodnost G. V resničnem vodu oba nista preprosti konstanti, pač pa sta komplicirani funkciji časa $R(t)$ in $G(t)$. Oba je lažje zapisati v frekvenčnem prostoru kot $R(\omega)$ in $G(\omega)$, zato se na opis dogajanja v vodu z izgubami vrnemo kasneje v frekvenčnem prostoru.

Vod z izgubami



$$\frac{dU(z)}{dz}=-j\omega L/l\cdot I(z)-R/l\cdot I(z)$$

$$\frac{dI(z)}{dz}=-j\omega C/l\cdot U(z)-G/l\cdot U(z)$$

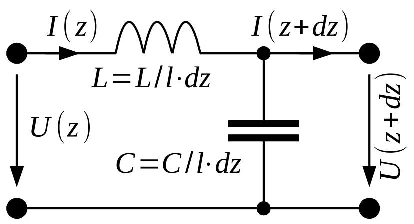
$$\frac{d^2U(z)}{dz^2}=(j\omega L/l+R/l)(j\omega C/l+G/l)\cdot U(z)=-k^2U(z)$$

$$k=\beta-j\alpha=\sqrt{-(j\omega L/l+R/l)\cdot(j\omega C/l+G/l)}$$

$$U(z)=U_N(0)\cdot e^{-\alpha z}\cdot e^{-j\beta z}+U_O(0)\cdot e^{+\alpha z}\cdot e^{+j\beta z}$$

$$u(z,t)=Re\left[U_N(0)\cdot e^{-\alpha z}\cdot e^{j(\omega t-\beta z)}+U_O(0)\cdot e^{+\alpha z}\cdot e^{j(\omega t+\beta z)}\right]$$

Brezizgubni vod



$$\frac{d^2U(z)}{dz^2}=-\omega^2 L/l\cdot C/l\cdot U(z)=-k^2U(z)$$

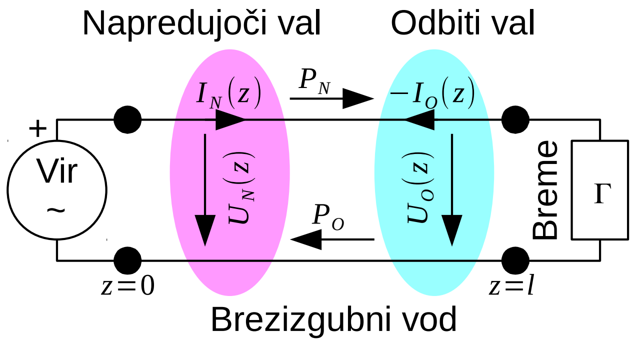
$$k=\beta=\omega\sqrt{L/l\cdot C/l}=\frac{\omega}{v}$$

$$U(z)=U_N(0)\cdot e^{-j\beta z}+U_O(0)\cdot e^{+j\beta z}$$

$$u(z,t)=Re\left[U_N(0)\cdot e^{j(\omega t-\beta z)}+U_O(0)\cdot e^{j(\omega t+\beta z)}\right]$$

Napredujoči val

Odbiti (povratni) val



$$U(z)=U_N(z)+U_N(z)$$

$$I(z)=I_N(z)+I_O(z)$$

$$\frac{U_N(z)}{I_N(z)}=-\frac{U_O(z)}{I_O(z)}=Z_K=\sqrt{\frac{L/l}{C/l}}$$

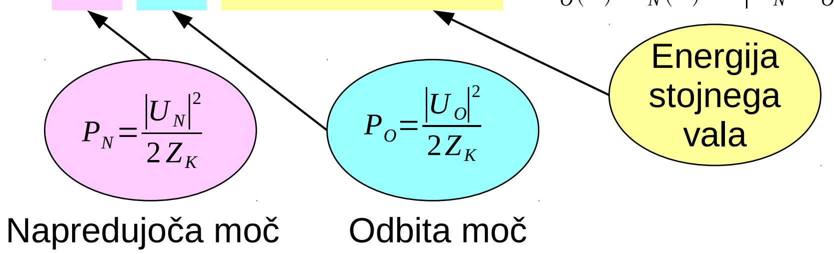
$$P=\frac{U(z)\cdot I(z)^*}{2}=\frac{1}{2}\cdot\left[U_N(0)\cdot e^{-j\beta z}+U_O(0)\cdot e^{+j\beta z}\right]\cdot\left[\frac{U_N(0)^*}{Z_K}\cdot e^{+j\beta z}-\frac{U_O(0)^*}{Z_K}\cdot e^{-j\beta z}\right]$$

$$P=\frac{|U_N|^2}{2Z_K}-\frac{|U_O|^2}{2Z_K}+j\frac{|U_N\cdot U_O|}{Z_K}\cdot\sin(2\beta l+\varphi)$$

$$U_N(0)\cdot U_O(0)^*=|U_N\cdot U_O|\cdot e^{-j\varphi}$$

$$U_O(0)\cdot U_N(0)^*=|U_N\cdot U_O|\cdot e^{+j\varphi}$$

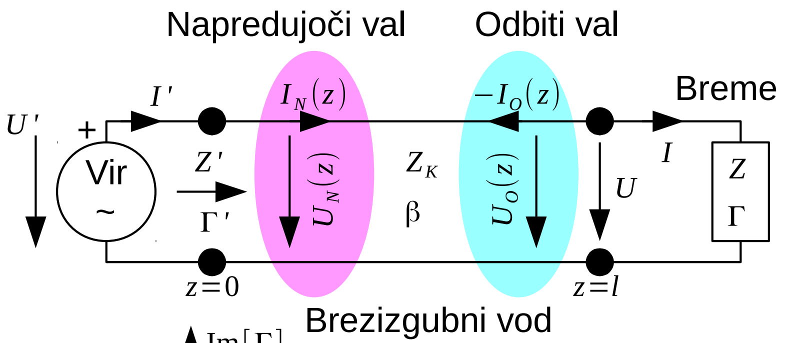
Moči valov



$$\mathrm{Re}[P]=P_N-P_O$$

$$P_O=|\Gamma|^2\cdot P_N$$

$$\mathrm{Re}[P]=P_N\cdot(1-|\Gamma|^2)$$

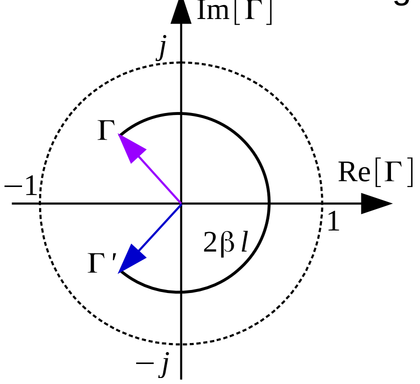


Brezizgubni vod

$$U_N(z)=U_N(0)\cdot e^{-j\beta z}$$

$$U_O(z)=U_O(0)\cdot e^{+j\beta z}$$

$$\frac{U_N}{I_N}=\frac{-U_O}{I_O}=Z_K=\sqrt{\frac{L/l}{C/l}}$$



Pasivno breme

$$\mathrm{Re}[Z]=R\geq 0$$

$$|\Gamma|\leq 1$$

$$\Gamma=\frac{Z-Z_K}{Z+Z_K}=\frac{Y_K-Y}{Y_K+Y}=\frac{U_O(l)}{U_N(l)}$$

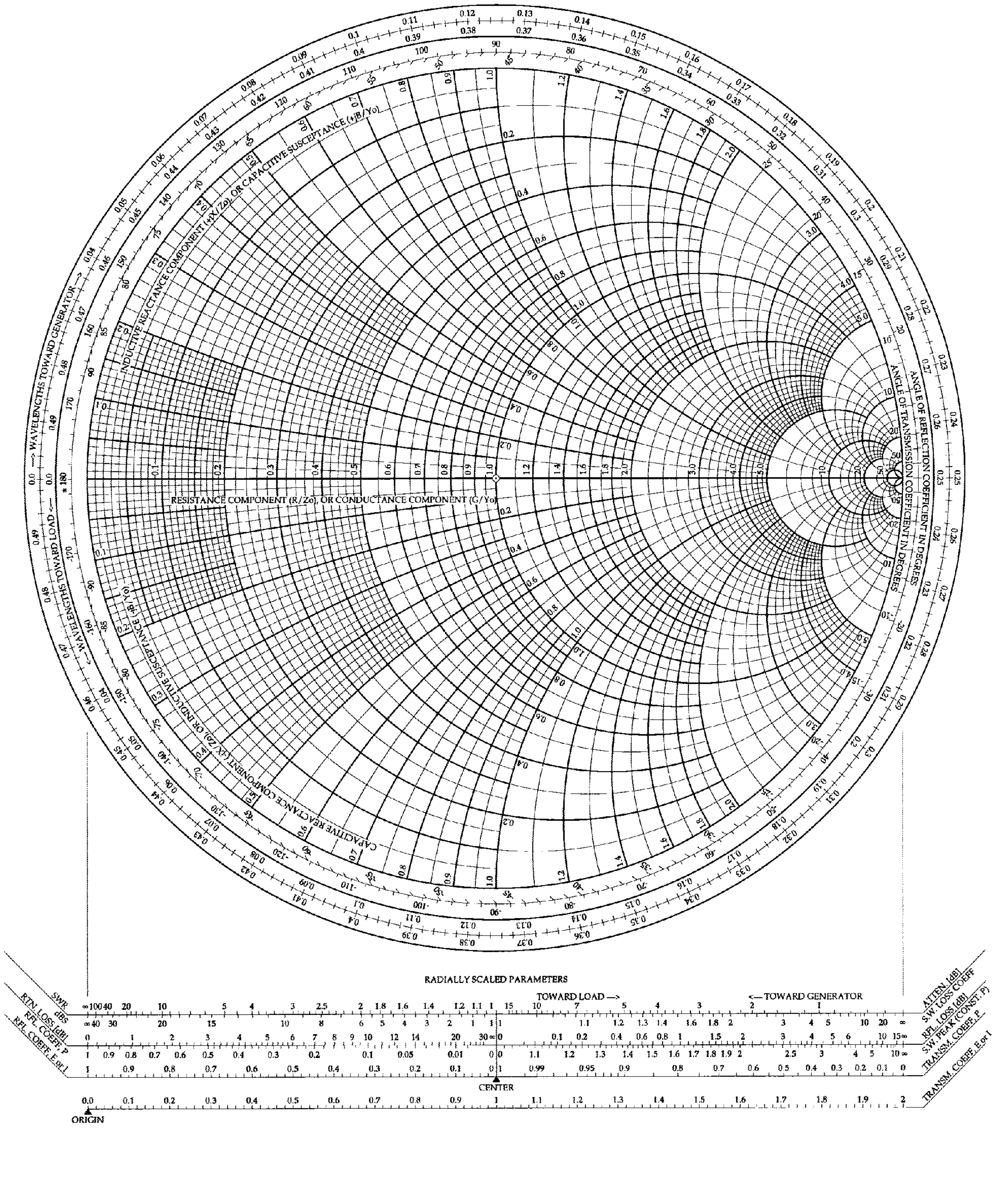
$$\Gamma'=\frac{U_O(0)}{U_N(0)}=\Gamma\cdot e^{-j2\beta l}$$

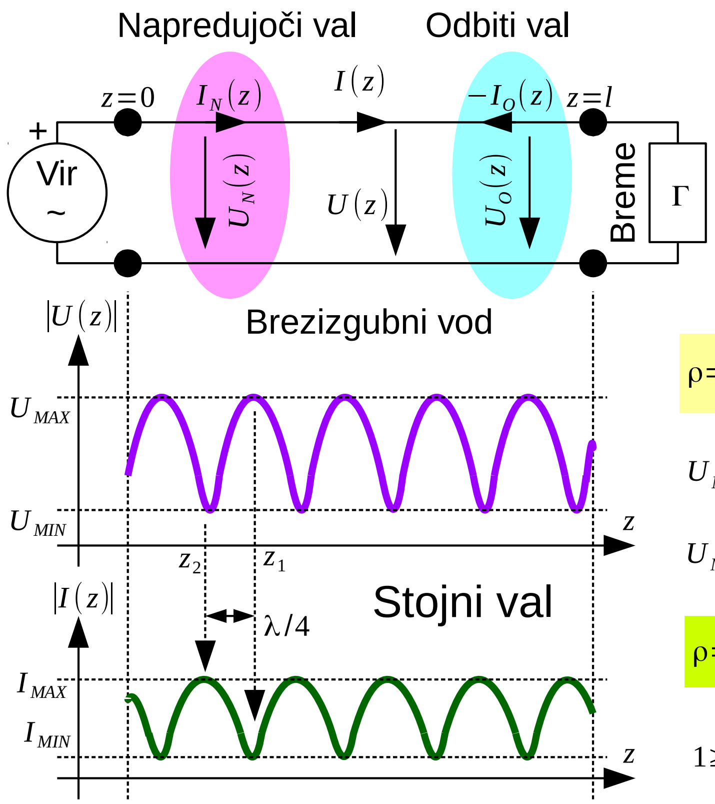
$$Z'=Z_K\cdot\frac{1+\Gamma'}{1-\Gamma'}$$

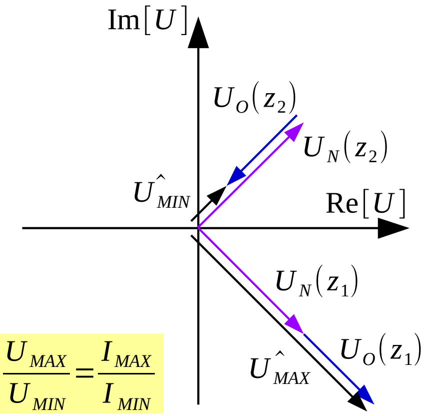
$$Z'=Z_K\cdot\frac{1+\frac{Z-Z_K}{Z+Z_K}\cdot e^{-j2\beta l}}{1-\frac{Z-Z_K}{Z+Z_K}\cdot e^{-j2\beta l}}=Z_K\cdot\frac{Z\cos(\beta l)+jZ_K\sin(\beta l)}{Z_K\cos(\beta l)+jZ\sin(\beta l)}$$

Smith-ov diagram

Smith-ov diagram:
impedanca/admitanca v merilu odbojnosti







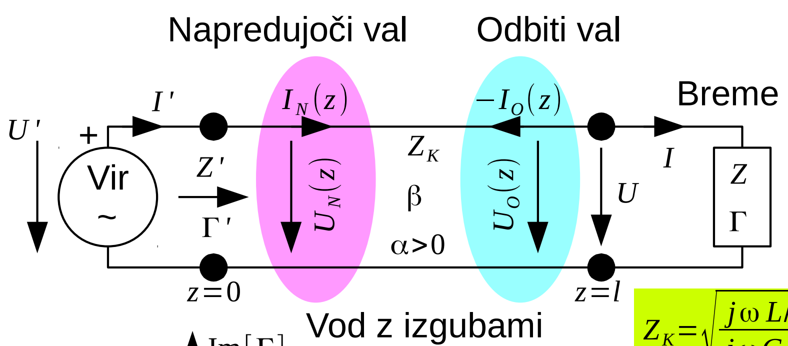
$$\rho=\frac{U_{MAX}}{U_{MIN}}=\frac{I_{MAX}}{I_{MIN}}$$

$$U_{MAX}=|U_N|+|U_O|=|U_N|\cdot(1+|\Gamma|)$$

$$U_{MIN}=|U_N|-|U_O|=|U_N|\cdot(1-|\Gamma|)$$

$$\rho=\left|\frac{1+|\Gamma|}{1-|\Gamma|}\right| \qquad 1\le\rho\le\infty$$

$$1\ge|\Gamma|=\frac{\rho-1}{\rho+1} \qquad 1\le|\Gamma|=\frac{\rho+1}{\rho-1}$$



Majhne izgube

$R/l \ll \omega L/l$

$G/l \approx 0$

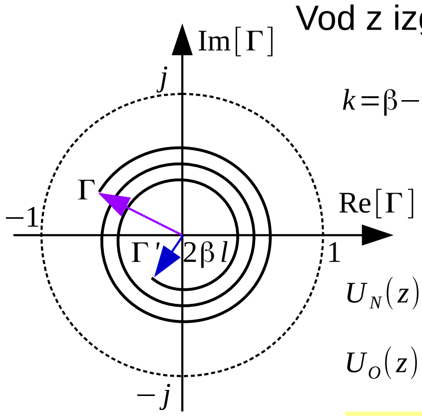
$Z_K \approx \sqrt{\frac{L/l}{C/l}}$

$\beta \approx \omega\sqrt{L/l \cdot C/l}$

$\alpha \approx \frac{R/l}{2Z_K}$

$$Z_K=\sqrt{\frac{j\omega L/l+R/l}{j\omega C/l+G/l}}$$

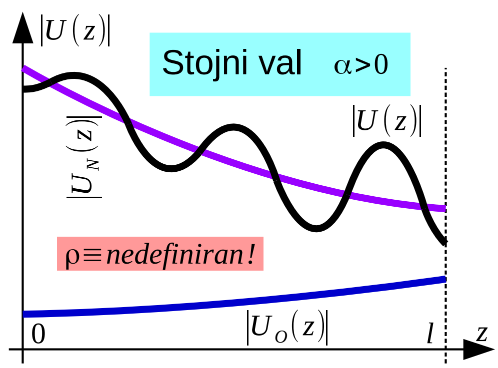
$$k=\beta-j\alpha=\sqrt{-(j\omega L/l+R/l)\cdot(j\omega C/l+G/l)}$$



$$U_N(z)=U_N(0)\cdot e^{-\alpha z}\cdot e^{-j\beta z}$$

$$U_O(z)=U_O(0)\cdot e^{+\alpha z}\cdot e^{+j\beta z}$$

$$\Gamma'=\Gamma\cdot e^{-2\alpha l}\cdot e^{-j2\beta l}$$



Vod z izgubami

Neper

$$a_{Np} = \ln \frac{|U_1|}{|U_2|}$$

$$P = \frac{|U|^2}{2 Z_K} \qquad |U| = \sqrt{2 Z_K P}$$

$$a_{Np} = \ln \sqrt{\frac{P_1}{P_2}} = \frac{1}{2} \ln \frac{P_1}{P_2}$$

Prilagoditev (povratno slabljenje, return loss)

$$\Gamma_{dB} = 10 \cdot \log |\Gamma|^2 = 20 \cdot \log |\Gamma|$$

Decibel

$$a_{dB} = 10 \cdot \log \frac{P_1}{P_2}$$

$$a_{dB} = 10 \cdot \log \left|\frac{U_1}{U_2}\right|^2 = 20 \cdot \log \left|\frac{U_1}{U_2}\right|$$

$$a_{dB} = \frac{20}{\ln 10} \cdot \ln \frac{|U_1|}{|U_2|} = \frac{20}{2.3026} \cdot a_{Np}$$

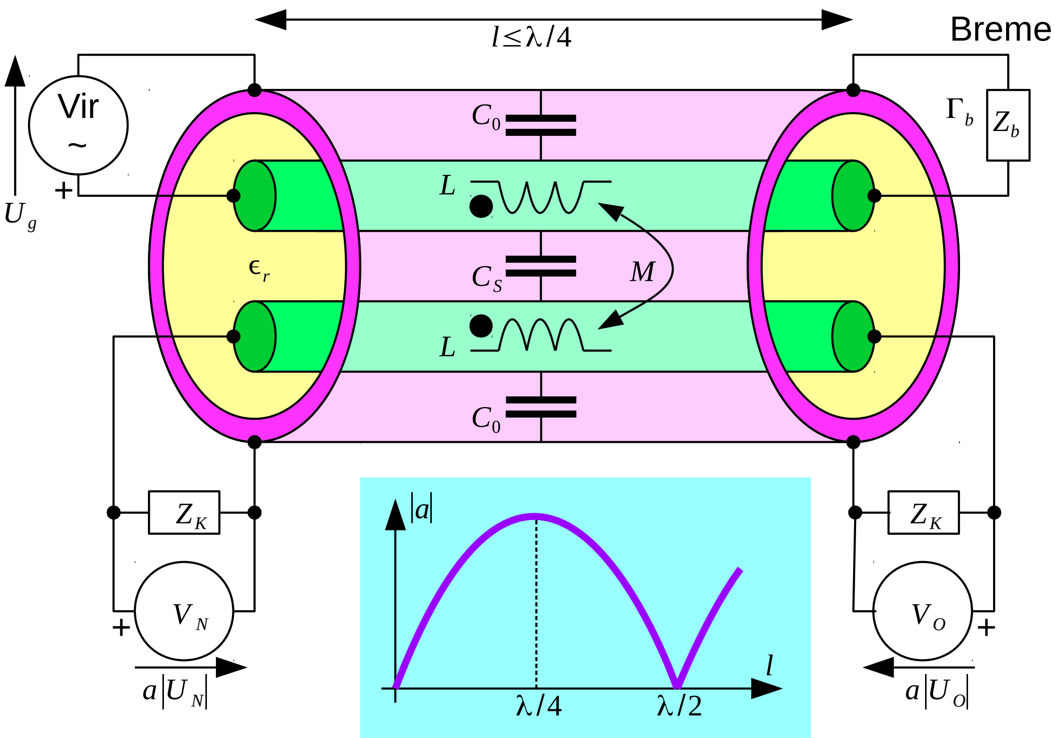
Slabljenje voda

$$|U_N(z)| = |U_N(0)| \cdot e^{-\alpha z} \qquad \alpha \approx \frac{R/l}{2 Z_K}$$

$$a_{Np} = \ln \frac{|U_N(0)|}{|U_N(l)|} = \alpha l \qquad a_{Np}/l = \alpha$$

$$a_{dB} = \frac{20}{\ln 10} \cdot a_{Np} = \frac{20}{\ln 10} \cdot \alpha l \qquad a_{dB}/l = \frac{20}{\ln 10} \cdot \alpha$$

Logaritemske merske enote



Protismerni sklopnik

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