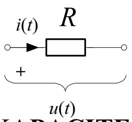
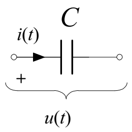
OTPOR



$$i(t)=\frac{u(t)}{R} \qquad u(t)=R\cdot i(t)$$

KAPACITET

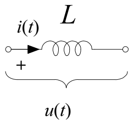


$$i(t)=C\frac{\mathrm{d}\,u(t)}{\mathrm{d}\,t}$$

$$u(t)=\frac{1}{C}\int_{-\infty}^{t} i(\tau)\mathrm{d}\tau=u_C(0)+\frac{1}{C}\int_{0}^{t} i(\tau)\mathrm{d}\tau$$

$$Z(s)=\frac{1}{sC}$$

INDUKTIVITET

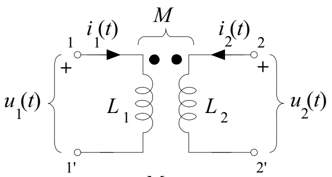


$$i(t)=\frac{1}{L}\int_{-\infty}^{t} u(\tau)\mathrm{d}\tau=i_L(0)+\frac{1}{L}\int_{0}^{t} u(\tau)\mathrm{d}\tau$$

$$u(t)=L\frac{\mathrm{d}\,i(t)}{\mathrm{d}\,t}$$

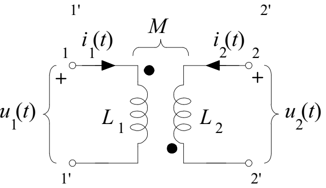
$$Z(s)=sL$$

- ***Transformator*** → dva induktiviteta koji su međuinduktivno vezani



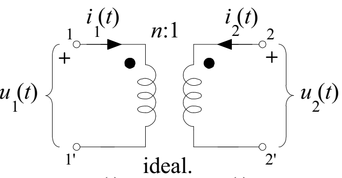
$$u_1(t)=L_1\frac{\mathrm{d}i_1}{\mathrm{d}t}+M\frac{\mathrm{d}i_2}{\mathrm{d}t}$$

$$u_2(t)=+M\frac{\mathrm{d}i_1}{\mathrm{d}t}+L_2\frac{\mathrm{d}i_2}{\mathrm{d}t}$$



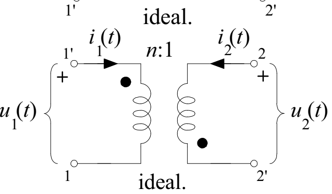
$$u_1(t)=L_1\frac{\mathrm{d}i_1}{\mathrm{d}t}-M\frac{\mathrm{d}i_2}{\mathrm{d}t}$$

$$u_2(t)=-M\frac{\mathrm{d}i_1}{\mathrm{d}t}+L_2\frac{\mathrm{d}i_2}{\mathrm{d}t}$$



$$u_1(t)=n\cdot u_2(t)$$

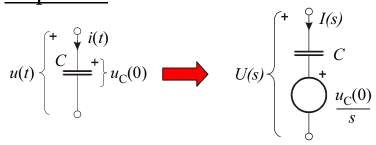
$$i_1(t)=-\frac{1}{n}\cdot i_2(t)$$



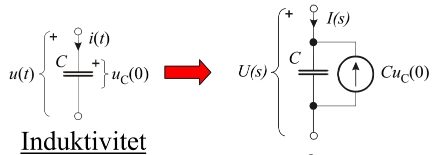
$$u_1(t)=-n\cdot u_2(t)$$

$$i_1(t)=\frac{1}{n}\cdot i_2(t)$$

Kapacitet

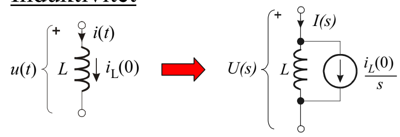


$$U(s)=\frac{1}{sC}I(s)+\frac{u_C(0)}{s}$$

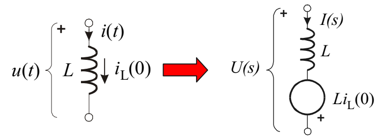


$$I(s)=sCU(s)-Cu_C(0)$$

Induktivitet

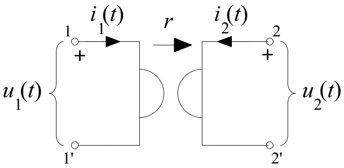


$$I(s)=\frac{1}{sL}U(s)+\frac{i_L(0)}{s}$$



$$U(s)=sLI(s)-Li_L(0)$$

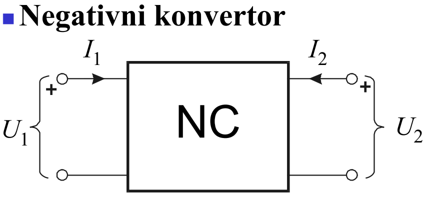
- **Girator** je četveropol određen simbolom



$$u_1(t)=r\cdot i_2(t)$$

$$u_2(t)=-r\cdot i_1(t)$$

- **Negativni konvertor**

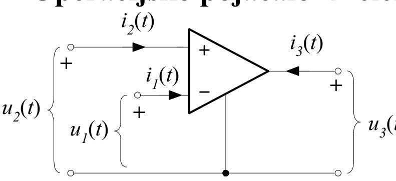


$$u_1(t)=k_1\cdot u_2(t)$$

$$i_2(t)=k_2\cdot i_1(t)$$

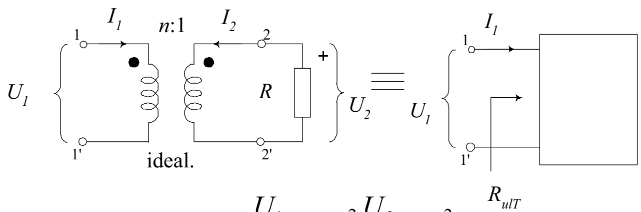
$$k=k_1\cdot k_2$$

- **Operacijsko pojačalo** → element sa 3 prilaza.



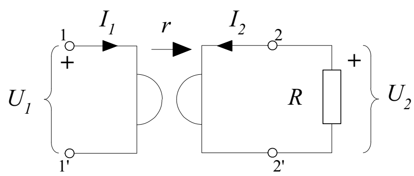
$$u_2-u_1=\frac{u_3}{A}\to 0$$

→transformator **mijenja** vrijednost otpora



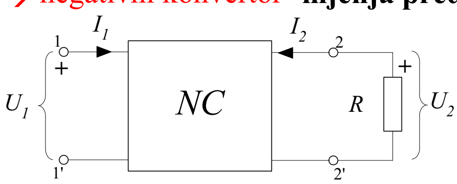
$$R_{ul_T}=\frac{U_1}{I_1}=-n^2\frac{U_2}{I_2}=n^2R$$

→girator **invertira** vrijednost otpora



$$R_{ul_G}=\frac{U_1}{I_1}=-r^2\frac{I_2}{U_2}=\frac{r^2}{R}$$

→ negativni konvertor **mjenja predznak**



$$R_{ul_{NK}}=\frac{U_1}{I_1}=\frac{k_1\cdot U_2}{k_2^{-1}\cdot I_2}=-k_1k_2R$$

$\mathbf{U}_g = \mathbf{Z}_p \cdot \mathbf{I}_p$

U_g → vektor naponskih izvora i početnih veličina u petljama

$$\mathbf{U}_p = \begin{bmatrix} U_{g1}(s) + \frac{u_{C5}(0)}{s} - L_2 i_{L2}(0) \\ L_2 i_{L2}(0) \\ -\frac{u_{C5}(0)}{s} \end{bmatrix}$$

$\mathbf{Z}_p$ kvadratna matrica → ***matrica impedancija petlji*** :

$$\mathbf{Z}_p = \begin{bmatrix} R_1 + sL_2 + \frac{1}{sC_5} & -sL_2 & -\frac{1}{sC_5} \\ -sL_2 & R_3 + R_4 + sL_2 & -R_4 \\ -\frac{1}{sC_5} & -R_4 & R_4 + R_6 + \frac{1}{sC_5} \end{bmatrix}$$

- Element glavne dijagonale
  - → suma impedancija u promatranoj petlji.
- Elementi izvan glavne dijagonale
  - → impedancije, zajedničke dvjema petljama.
- Elementi izvan glavne dijagonale imaju negativan predznak
  → posljedica odabira istoga smjera za sve struje petlji.

I_p → vektor struja petlji

$$\mathbf{I}_p = \begin{bmatrix} I_{p1} \\ I_{p2} \\ I_{p3} \end{bmatrix}$$

$\mathbf{I}_g = \mathbf{Y}_v \cdot \mathbf{U}_v$

$\mathbf{I}_g$ → vektor strujnih izvora

$$\mathbf{I}_g = \begin{bmatrix} \frac{U_{g1}(s)}{R_1} + \frac{i_{L2}(0)}{s} \\ -\frac{i_{L2}(0)}{s} - C_5 u_{C5}(0) \\ 0 \end{bmatrix}$$

$\mathbf{Y}_v$ kvadratna matrica → **matrica admitancija čvorišta**.

$$\mathbf{Y}_v = \begin{bmatrix} \frac{1}{R_1} + \frac{1}{sL_2} + \frac{1}{R_3} & -\frac{1}{sL_2} & -\frac{1}{R_3} \\ -\frac{1}{sL_2} & \frac{1}{sL_2} + \frac{1}{R_4} + sC_5 & -\frac{1}{R_4} \\ -\frac{1}{R_3} & -\frac{1}{R_4} & \frac{1}{R_3} + \frac{1}{R_4} + \frac{1}{R_6} \end{bmatrix}$$

- Element glavne dijagonale matrice
- → suma admitancija grana vezanih na promatrano čvorište.
- Elementi izvan glavne dijagonale
- → admitancije grana, spojenih na dva promatrana čvorišta.
- Negativni predznaci elemenata izvan glavne dijagonale
  →posljedica odabira orijentacija napona čvorišta.

$\mathbf{U}_v$ → vektor napona čvorišta

$$\mathbf{U}_v = \begin{bmatrix} U_{v1} \\ U_{v2} \\ U_{v3} \end{bmatrix}$$

Tablica $\mathcal{L}$ transformacije

$1 \circ\!\!-\!\!\bullet \frac{1}{s}$

$t \circ\!\!-\!\!\bullet \frac{1}{s^2}$

$e^{-at} \circ\!\!-\!\!\bullet \frac{1}{s+a}$

$\frac{1}{b-a}(e^{-at} - e^{-bt}) \circ\!\!-\!\!\bullet \frac{1}{(s+a)(s+b)}$

$\frac{1}{a-b}(ae^{-at} - be^{-bt}) \circ\!\!-\!\!\bullet \frac{s}{(s+a)(s+b)}$

$\frac{1}{a}e^{-bt}\sin(at) \circ\!\!-\!\!\bullet \frac{1}{(s+b)^2 + a^2}$

$e^{-bt}\left(\cos(at) - \frac{b}{a}\sin(at)\right) \circ\!\!-\!\!\bullet \frac{s}{(s+b)^2 + a^2}$

$\sin \omega t \circ\!\!-\!\!\bullet \frac{\omega}{s^2 + \omega^2}$, $\quad \cos \omega t \circ\!\!-\!\!\bullet \frac{s}{s^2 + \omega^2}$,

$\mathrm{sh}\, \omega t \circ\!\!-\!\!\bullet \frac{\omega}{s^2 - \omega^2}$, $\quad \mathrm{ch}\, \omega t \circ\!\!-\!\!\bullet \frac{s}{s^2 - \omega^2}$.

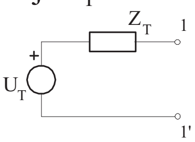
- **Kirchhoffov zakon za struje** (KZS) i
  - Algebarska suma struja, koje se sastaju u jednom čvorištu mreže s koncentriranim elementima u svakom je trenutku jednaka nuli.
  - Strujama orijentiranima od čvorišta pridružiti
    - ***pozitivan predznak***
  - Strujama orijentiranima prema čvorištu pridružiti
    - ***negativan predznak***.
  - za mrežu s N_v čvorišta broj linearno neovisnih jednadžbi KZS jednak N_v-1.

- **Kirchhoffov zakon za napone** (KZN).
  - Za svaku mrežu moguće je napisati onoliko jednadžbi KZN koliko ta mreža sadrži zatvorenih kontura.
  - Za mrežu s N_v čvorišta i N_b grana, broj linearno neovisnih jednadžbi KZN jednak je

$$N_b-(N_v-1)=N_b-N_v+1$$

Theveninov teorem

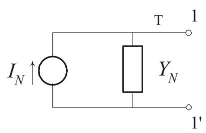
- Svakoj linearnoj, vremenski nepromjenjivoj, aktivnoj mreži s jednim prilazom moguće je odrediti ekvivalentni dvopol koji se sastoji od jednog neovisnog naponskog izvora U_T i jedne serijski spojene impedancije Z_T



- Napon U_T naponskog izvora jednak je naponu na otvorenim priključnicama promatrane mreže.
- Impedancija Z_T je jednaka impedanciji gledanoj sa prilaza mreže uz
- ugašene sve neovisne izvore (ovisni izvori ostaju u krugu) i
- uz početne uvjete na kapacitetima i induktivitetima jednake nuli.

Nortonov teorem

- Svakoj linearnoj, vremenski nepromjenjivoj, aktivnoj mreži s jednim prilazom moguće je odrediti ekvivalentni dvopol koji se sastoji od jednog neovisnog strujnog izvora I_N i jedne paralelno spojene admitancije Y_N



- Struja I_N strujnog izvora jednaka je struji kroz kratko spojene priključnice promatrane mreže
- Admitancija Y_N je jednaka admitanciji gledanoj sa prilaza mreže uz ugašene sve neovisne izvore i uz početne uvjete na kapacitetima i induktivitetima jednake nuli.

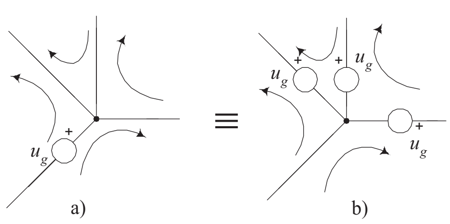
Teorem superpozicije

- Odziv $y(t)$ linearnog kruga na istovremeno djelovanje n različitih pobuda $x_1, x_2, x_3,...,x_n$, koje kad se primijene pojedinačno daju odzive $y_1, y_2, y_3,...y_n$, jednak je sumi svih tih odziva, tj.

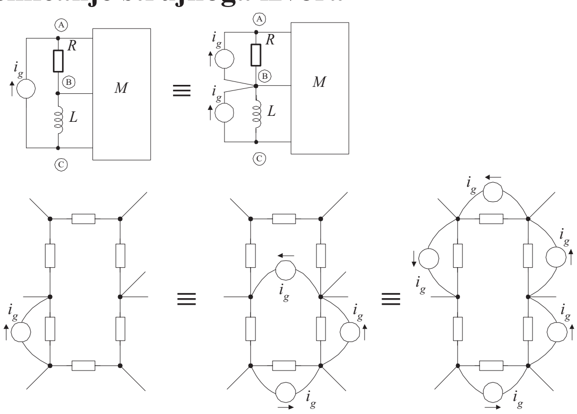
$$y(t)=\sum_{k=1}^{n} y_k(t)$$

- Pobude mogu biti neovisni naponski ili strujni izvori, kao i početni naponi na kapacitetima i struje u induktivitetima.

posmicanjem naponskoga izvora.

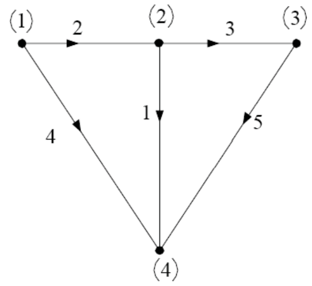


Posmicanje strujnoga izvora



- **b** → grana (odnosno grane)
- **v** → čvor (čvorovi)
- **p** → petlja (petlje)
- **t** → grana stabla (grane stabla)
- **s** → spona (spone)
- **r** → rez (rezovi)
- **N** → broj nečega (npr. N_b – broj grana)

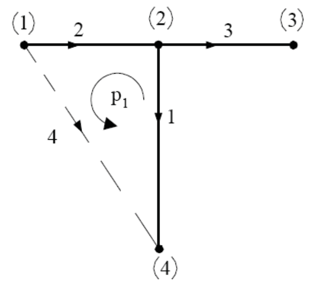
- $N_t = N_r = N_v - 1$
- $N_s = N_p = N_b - N_v + 1$

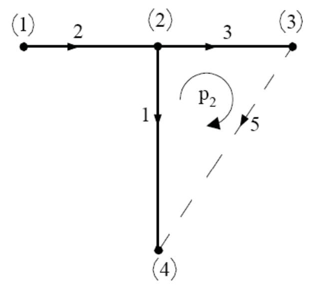


$$\mathbf{A} = \begin{array}{c} \begin{array}{ccccc} g1 & g2 & g3 & g4 & g5 \end{array} \\ \begin{bmatrix} 0 & 1 & 0 & 1 & 0 \\ 1 & -1 & 1 & 0 & 0 \\ 0 & 0 & -1 & 0 & 1 \end{bmatrix} \end{array} \begin{array}{c} \\ č1 \\ č2 \\ č3 \end{array}$$

ulazi: -1

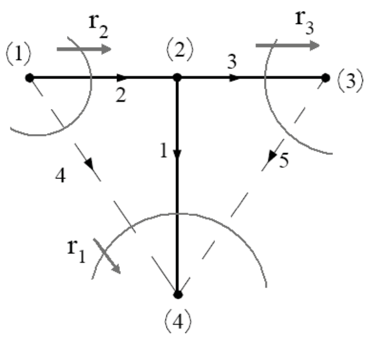
- $\mathbf{A_a}$ → matrica incidencije; veličine je $N_v \times N_b$
- **A** → reducirana matrica incidencije; veličine je $N_t \times N_b$
- **S** → spojna matrica; veličine je $N_s \times N_b$
- **Q** → rastavna matrica; veličine je $N_t \times N_b$





$$\mathbf{S} = \begin{array}{c} \begin{array}{ccccc} g1 & g2 & g3 & g4 & g5 \end{array} \\ \begin{bmatrix} -1 & -1 & 0 & 1 & 0 \\ -1 & 0 & 1 & 0 & 1 \end{bmatrix} \end{array} \begin{array}{c} \\ p1 \\ p2 \end{array}$$

u smjeru spone: 1



$$\mathbf{Q} = \begin{array}{c} \begin{array}{ccccc} g1 & g2 & g3 & g4 & g5 \end{array} \\ \begin{bmatrix} 1 & 0 & 0 & 1 & 1 \\ 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 1 \end{bmatrix} \end{array} \begin{array}{c} \\ r1 \\ r2 \\ r3 \end{array}$$

u smjeru reza: 1

Nepoznanice su:

- $\mathbf{U_b}$ → vektor stupac duljine N_b gdje svaki član matrice predstavlja jedan napon grane
- $\mathbf{U_v}$ → vektor stupac duljine N_v gdje svaki član matrice predstavlja jedan napon čvora
- $\mathbf{U_r}$ → vektor stupac duljine N_r gdje svaki član matrice predstavlja jedan napon reza
- $\mathbf{I_b}$ → vektor stupac duljine N_b gdje svaki član matrice predstavlja jednu struju grane
- $\mathbf{I_p}$ → vektor stupac duljine N_p gdje svaki član matrice predstavlja jednu struju petlje

$$\begin{bmatrix} a & b \\ c & d \end{bmatrix}^{-1} = \frac{1}{a \cdot d - b \cdot c} \cdot \begin{bmatrix} d & -b \\ -c & a \end{bmatrix}$$

Poznate matrice:

- $\mathbf{U_{0b}}$ → vektor stupac duljine N_b gdje svaki član matrice predstavlja vrijednost napona izvora i početnih uvjeta u grani
- $\mathbf{U_{0p}}$ → vektor stupac duljine N_p gdje svaki član matrice predstavlja vrijednost napona izvora i početnih uvjeta u petlji
- $\mathbf{I_{0b}}$ → vektor stupac duljine N_b gdje svaki član matrice predstavlja vrijednost struje izvora i početnih uvjeta u grani
- $\mathbf{I_{0v}}$ → vektor stupac duljine N_v gdje svaki član matrice predstavlja vrijednost struje izvora i početnih uvjeta čvora
- $\mathbf{I_{0r}}$ → vektor stupac duljine N_r gdje svaki član matrice predstavlja vrijednost struje izvora i početnih uvjeta reza
- $\mathbf{Z_b}$ → kvadratna matrica veličine $N_b \times N_b$; sadrži impedancije grana
- $\mathbf{Z_p}$ → kvadratna matrica veličine $N_p \times N_p$; sadrži impedancije petlji
- $\mathbf{Y_b}$ → kvadratna matrica veličine $N_b \times N_b$; sadrži admitancije grana
- $\mathbf{Y_v}$ → kvadratna matrica veličine $N_v \times N_v$; sadrži admitancije čvorova
- $\mathbf{Y_r}$ → kvadratna matrica veličine $N_r \times N_r$; sadrži admitancije rezova

Jednadžbe strujno naponskih relacija:

$$\mathbf{U}_b = \mathbf{Z}_b \cdot \mathbf{I}_b + \mathbf{U}_{0b}$$

$$\mathbf{I}_b = \mathbf{Y}_b \cdot \mathbf{U}_b + \mathbf{I}_{0b}$$

- Jednadžbe petlji → $\mathbf{Z}_p \cdot \mathbf{I}_p = \mathbf{U}_{op}$

$$\mathbf{Z}_p = \mathbf{S} \cdot \mathbf{Z}_b \cdot \mathbf{S}^T$$

$$\mathbf{U}_{0p} = -\mathbf{S} \cdot \mathbf{U}_{0b}$$

- Jednadžbe čvorova → $\mathbf{Y}_v \cdot \mathbf{U}_v = \mathbf{I}_{ov}$

$$\mathbf{Y}_v = \mathbf{A} \cdot \mathbf{Y}_b \cdot \mathbf{A}^T$$

$$\mathbf{I}_{0v} = -\mathbf{A} \cdot \mathbf{I}_{0b}$$

- Jednadžbe rezova → $\mathbf{Y}_r \cdot \mathbf{U}_r = \mathbf{I}_{or}$

$$\mathbf{Y}_r = \mathbf{Q} \cdot \mathbf{Y}_b \cdot \mathbf{Q}^T$$

$$\mathbf{I}_{0r} = -\mathbf{Q} \cdot \mathbf{I}_{0b}$$

$$H(s)=\frac{\textbf{odziv}}{\textbf{pobuda}}$$

$$\alpha(\omega)=20\log|H(j\omega)|$$

$$H(s)=|H(s)|e^{j\angle H(s)}$$

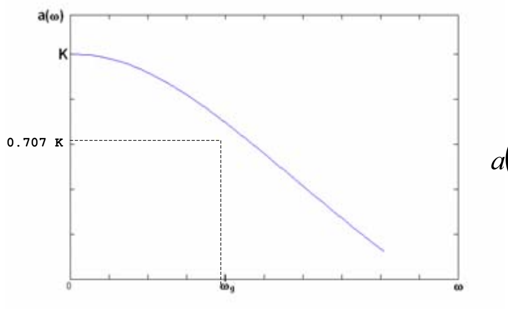
$$|H(j\omega)|=\sqrt{(Re[H(j\omega)])^2+(Im[H(j\omega)])^2}$$

$$\angle H(j\omega)=\arctan\left(\frac{Im[H(j\omega)]}{Re[H(j\omega)]}\right)$$

1) Niskopropusni (NP)

$$H(s)=K\cdot\frac{\omega_g}{s+\omega_g}$$

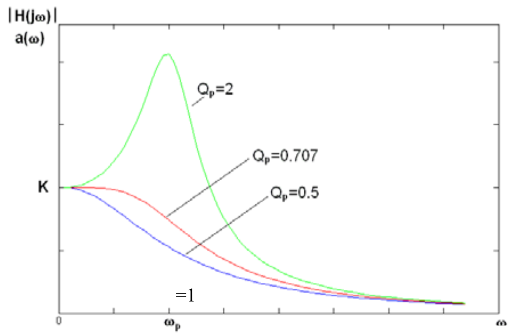
$$a(\omega)=\frac{K}{\sqrt{1+\left(\frac{\omega}{\omega_g}\right)^2}}$$



$$a(\omega_g)=\frac{K}{\sqrt{2}}=0{,}707K$$

$$H(s)=K\frac{\omega_p^2}{s^2+\frac{\omega_p}{Q_p}s+\omega_p^2}$$

$$a(\omega)=K\frac{1}{\sqrt{\left(1-\left(\frac{\omega}{\omega_p}\right)^2\right)^2+\left(\frac{1}{Q_p}\frac{\omega}{\omega_p}\right)^2}}$$

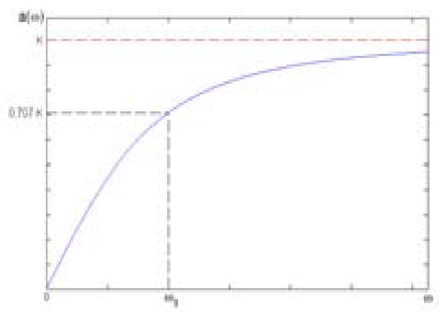


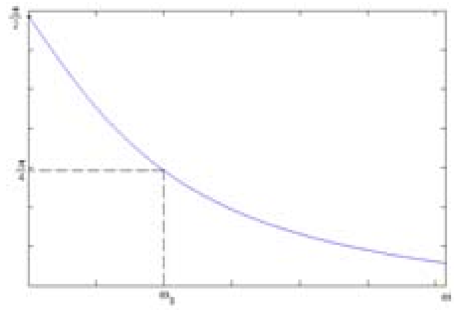
2) Visokopropusni (VP)

$$H_{VP}(s)=\frac{K\cdot s}{s+\omega_g}$$

$$a(\omega)=K\frac{|\omega|}{\sqrt{\omega^2+\omega_g^2}}$$

$$\varphi(\omega)=\frac{\pi}{2}-arctg\left(\frac{\omega}{\omega_g}\right)$$

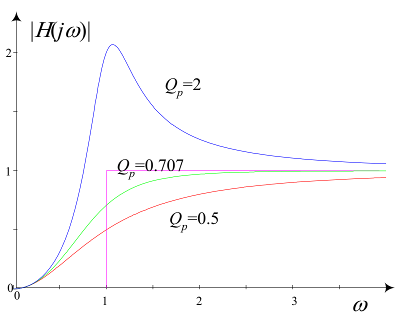


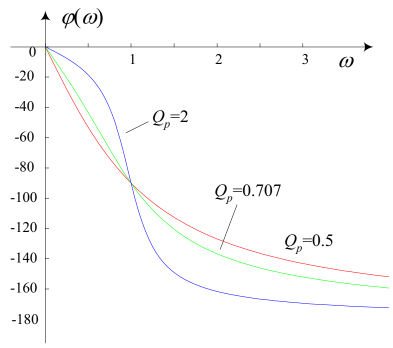


$$H(s)=K\cdot\frac{s^2}{s^2+\frac{\omega_p}{Q_p}s+\omega_p^2}$$

$$a(\omega)=|H(j\omega)|=K\frac{\omega^2}{\sqrt{(\omega_p^2-\omega^2)^2+\left(\frac{\omega\omega_p}{Q_p}\right)^2}}$$

$$\varphi(\omega)=\pi-\text{arctg}\frac{\omega_p\cdot\omega/Q_p}{\omega_p^2-\omega^2}$$



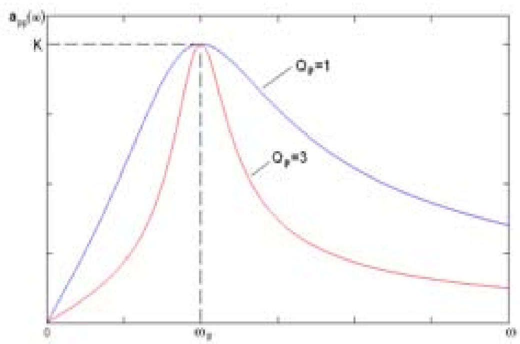


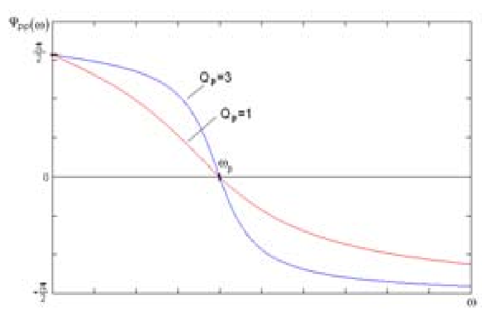
3) Pojasno propusni (PP)

$$H_{PP}(s)=K\cdot\frac{s\cdot\frac{\omega_p}{Q_p}}{s^2+\frac{\omega_p}{Q_p}s+\omega_p^2}$$

$$a_{pp}(\omega)=\frac{K}{\sqrt{1+Q_P^2\left(\frac{\omega}{\omega_p}-\frac{\omega_p}{\omega}\right)^2}}$$

$$\varphi_{pp}(\omega)=-\text{arctg}\left[Q\left(\frac{\omega}{\omega_p}-\frac{\omega_p}{\omega}\right)\right]$$



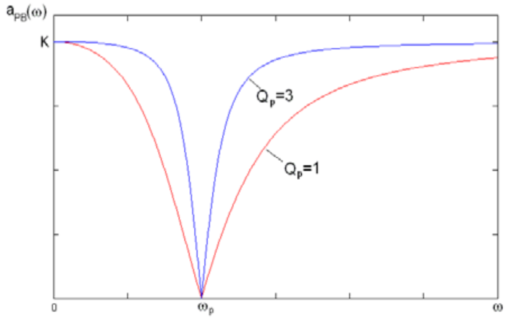


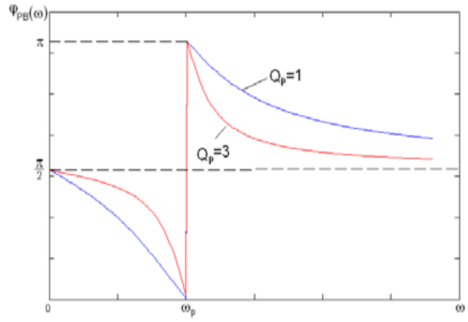
4) Pojasna brana (PB)

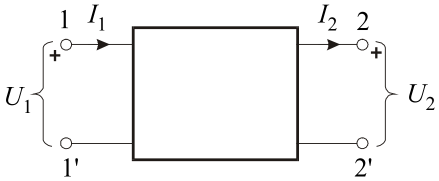
$$H_{PB}(s)=K\cdot\frac{s^2+\omega_p^2}{s^2+\frac{\omega_p}{Q_p}s+\omega_p^2}$$

$$a_{PB}(\omega)=K\cdot\frac{Q_p\left|\frac{\omega_p}{\omega}-\frac{\omega}{\omega_p}\right|}{\sqrt{1+Q_p^2\left(\frac{\omega_p}{\omega}-\frac{\omega}{\omega_p}\right)^2}}$$

$$\varphi_{PB}(\omega)=\pi\,S(\omega-\omega_p)-\mathrm{arctg}\left(Q_p\left(\frac{\omega_p}{\omega}-\frac{\omega}{\omega_p}\right)\right)$$





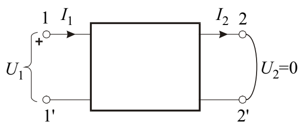


Strujne jednadžbe četveropola

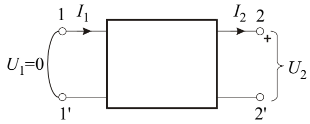
$$\begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} y_{11} & -y_{12} \\ y_{21} & -y_{22} \end{bmatrix} \begin{bmatrix} U_1 \\ U_2 \end{bmatrix}$$

- y-parametri → iz četveropola na kratko

$$y_{11} = \left.\frac{I_1}{U_1}\right|_{U_2=0} \qquad y_{21} = \left.\frac{I_2}{U_1}\right|_{U_2=0}$$



$$y_{12} = -\left.\frac{I_1}{U_2}\right|_{U_1=0} \qquad y_{22} = -\left.\frac{I_2}{U_2}\right|_{U_1=0}$$

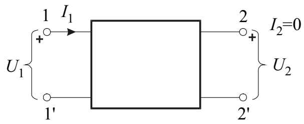


Naponske jednadžbe četveropola

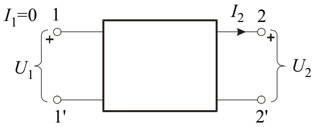
$$\begin{bmatrix} U_1 \\ U_2 \end{bmatrix} = \begin{bmatrix} z_{11} & -z_{12} \\ z_{21} & -z_{22} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix}$$

z-parametri → iz četveropola na prazno

$$z_{11} = \left.\frac{U_1}{I_1}\right|_{I_2=0} \qquad z_{21} = \left.\frac{U_2}{I_1}\right|_{I_2=0}$$



$$z_{12} = -\left.\frac{U_1}{I_2}\right|_{I_1=0} \qquad z_{22} = -\left.\frac{U_2}{I_2}\right|_{I_1=0}$$

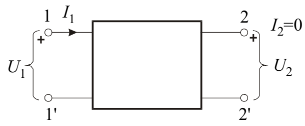


Prijenosne jednadžbe četveropola

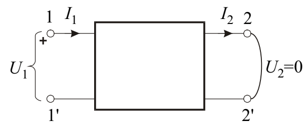
$$\begin{bmatrix} U_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} U_2 \\ I_2 \end{bmatrix}$$

a-parametri → iz 2-2' na prazno i na kratko

$$A = \left.\frac{U_1}{U_2}\right|_{I_2=0} \qquad C = \left.\frac{I_1}{U_2}\right|_{I_2=0}$$



$$B = \left.\frac{U_1}{I_2}\right|_{U_2=0} \qquad D = \left.\frac{I_1}{I_2}\right|_{U_2=0}$$



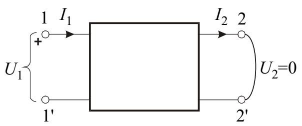
$$[z] = [y]^{-1}$$

Hibridne jednadžbe četveropola

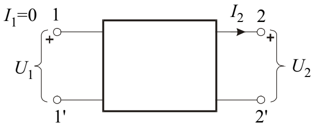
$$\begin{bmatrix} U_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} I_2 \\ U_2 \end{bmatrix}$$

h-parametri → iz 1-1' na prazno i 2-2' na kratko

$$h_{11} = \left.\frac{U_1}{I_1}\right|_{U_2=0} \qquad h_{21} = \left.\frac{I_2}{I_1}\right|_{U_2=0}$$



$$h_{12} = \left.\frac{U_1}{U_2}\right|_{I_1=0} \qquad h_{22} = \left.\frac{I_2}{U_2}\right|_{I_1=0}$$

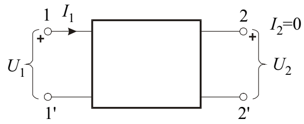


Hibridne jednadžbe četveropola

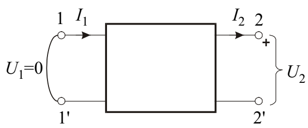
$$\begin{bmatrix} I_1 \\ U_2 \end{bmatrix} = \begin{bmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{bmatrix} \begin{bmatrix} U_1 \\ I_2 \end{bmatrix}$$

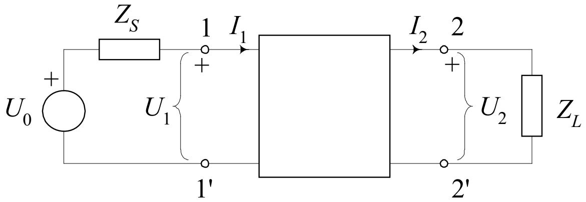
g-parametri → iz 2-2' na prazno i 1-1' na kratko

$$g_{11} = \left.\frac{I_1}{U_1}\right|_{I_2=0} \qquad g_{21} = \left.\frac{U_2}{U_1}\right|_{I_2=0}$$



$$g_{12} = \left.\frac{I_1}{I_2}\right|_{U_1=0} \qquad g_{22} = \left.\frac{U_2}{I_2}\right|_{U_1=0}$$





- Prijenosnu funkciju napona $H_u(s)=U_2(s)/U_1(s)$
- Prijenosnu funkciju struje $H_i(s)=I_2(s)/I_1(s)$
- Ekvivalentnu ulaznu impedanciju $Z_u(s)=U_1(s)/I_1(s)$
- Ekvivalentnu izlaznu impedanciju $Z_i(s)=-U_2(s)/I_2(s)|_{U_0=0}$

Prijenosne funkcije izražene z-parametrima

$$H_i(s) = \frac{I_2}{I_1} = \frac{z_{21}}{Z_L + z_{22}}$$

$$H_u(s) = \frac{U_2}{U_1} = \frac{Z_L z_{21}}{z_{11}(z_{22}+Z_L) - z_{12}z_{21}} = \frac{Z_L z_{21}}{\Delta_z + z_{11}Z_L}$$

$$H(s) = \frac{U_2}{U_0} = \frac{Z_L z_{21}}{(z_{11}+Z_s)(z_{22}+Z_L) - z_{12}z_{21}}$$

$$Z_{ul1} = \frac{U_1}{I_1} = z_{11} - z_{12}\cdot\frac{z_{21}}{Z_2 + z_{22}}$$

$$Z_{ul2} = -\frac{U_2}{I_2} = z_{22} - \frac{z_{12}z_{21}}{z_{11}+Z_1}$$

Prijenosne funkcije izražene y-parametrima

$$H_i(s) = \frac{I_2}{I_1} = \frac{Y_L y_{21}}{y_{11}(y_{22}+Y_L) - y_{12}y_{21}} = \frac{Y_L y_{21}}{\Delta_y + y_{11}Y_L}$$

$$H_u(s) = \frac{U_2}{U_1} = \frac{y_{21}}{Y_L + y_{22}}$$

$$Y_{ul1} = y_{11} - \frac{y_{12}y_{21}}{Y_2 + y_{22}}$$

$$Y_{ul2} = y_{22} - \frac{y_{12}y_{21}}{Y_1 + y_{11}}$$

Prijenosne funkcije izražene prijenosnim parametrima

$$H_i(s) = \frac{I_2}{I_1} = \frac{1}{CZ_L + D}$$

$$H_u(s) = \frac{U_2}{U_1} = \frac{Z_L}{AZ_L + B}$$

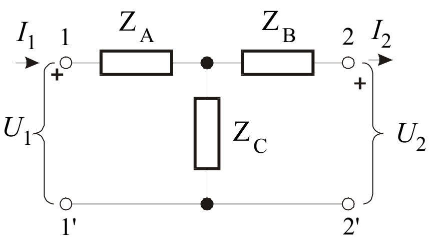
$$H(s) = \frac{U_2}{U_0} = \frac{Z_L}{AZ_L + B + Z_s(CZ_L + D)}$$

$$Z_{ul} = \frac{U_1}{I_1} = \frac{AZ_2 + B}{CZ_2 + D}$$

$$Z_{ul2} = -\frac{U_2}{I_2} = \frac{DZ_1 + B}{CZ_1 + A}$$

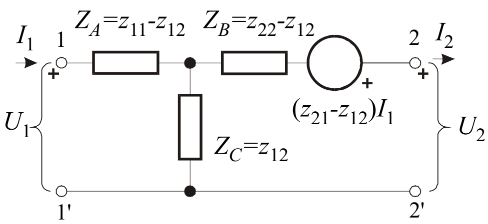
Ekvivalentni četveropol u T-spoju

Recipročni četveropol $z_{12}=z_{21}$



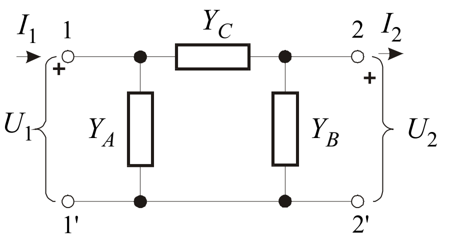
$$Z_A = z_{11} - z_{12}$$
$$Z_B = z_{22} - z_{12}$$
$$Z_C = z_{12} = z_{21}$$

Nerecipročni četveropol $z_{12} \neq z_{21}$



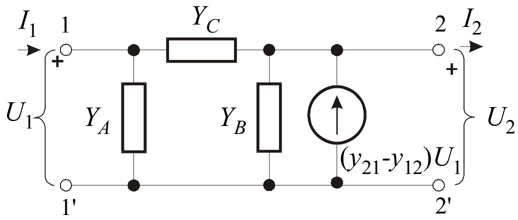
Ekvivalentni četveropol u Π-spoju

Recipročni četveropol $y_{12}=y_{21}$



$$Y_A = y_{11} - y_{12}$$
$$Y_B = y_{22} - y_{12}$$
$$Y_C = y_{12} = y_{21}$$

Nerecipročni četveropol $y_{12} \neq y_{21}$



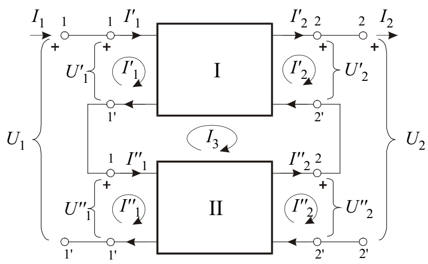
simetričan četveropol

$$z_{11} = z_{22}$$
$$y_{11} = y_{22}$$
$$A = D$$
$$\begin{vmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{vmatrix} = -1$$
$$\begin{vmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{vmatrix} = 1$$

recipročan četveropol

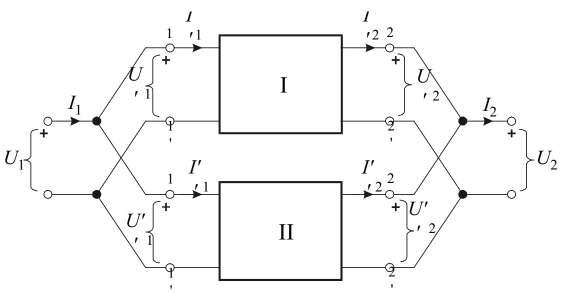
$$z_{12}=z_{21}$$
$$y_{12}=y_{21}$$
$$\Delta_A = \begin{vmatrix} A & B \\ C & D \end{vmatrix} = AD - BC = 1$$

Serijski spoj četveropola:



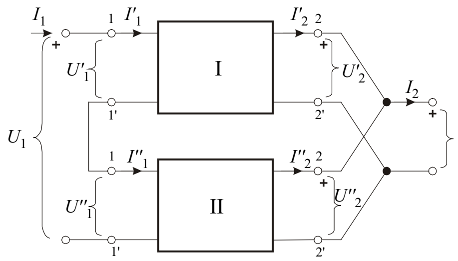
$$[z]=[z']+[z'']$$

Paralelni spoj četveropola:



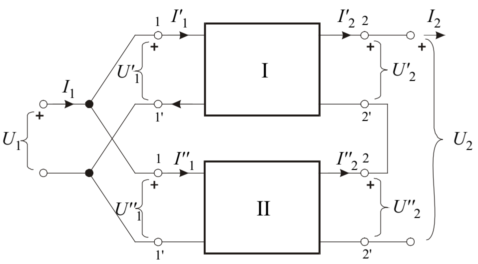
$$[y]=[y']+[y'']$$

Serijsko-paralelni spoj četveropola:



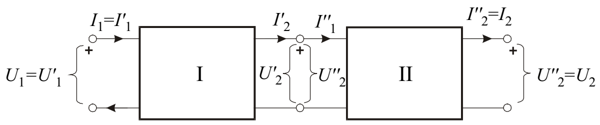
$$[h]=[h']+[h'']$$

Paralelno-serijski spoj četveropola:



$$[g]=[g']+[g'']$$

Lanac ili kaskada četveropola:



$$[a]=[a']\cdot[a'']$$

$$Z_0 = \sqrt{\frac{R+sL}{G+sC}}$$

$$\gamma = \sqrt{(R+sL)(G+sC)}$$

$$g = \gamma \cdot l$$

sinusoidalna pobuda:

$$Z_0 = \sqrt{\frac{R+j\omega L}{G+j\omega C}}$$

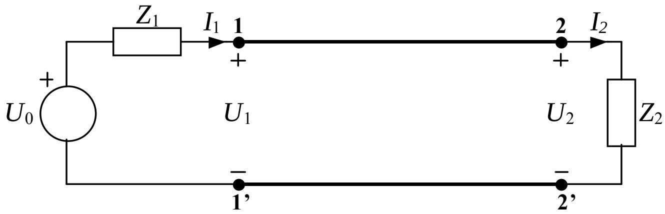
$$\gamma = \sqrt{(R+j\omega L)\ (G+j\omega C)}$$

$$U(l) = U(0)\operatorname{ch} g - I(0)Z_0 \operatorname{sh} g$$

$$I(l) = -U(0)\frac{\operatorname{sh} g}{Z_0} + I(0)\operatorname{ch} g$$

$$U(0) = U(l)\operatorname{ch} g + I(l)Z_0 \operatorname{sh} g$$

$$I(0) = U(l)\frac{\operatorname{sh} g}{Z_0} + I(l)\operatorname{ch} g$$



$$Z_{ul} = \frac{U_1}{I_1} = \frac{U_2 \operatorname{ch} g + I_2 Z_0 \operatorname{sh} g}{U_2 \dfrac{\operatorname{sh} g}{Z_0} + I_2 \operatorname{ch} g}$$

$$U_2 = I_2 \cdot Z_2$$

$$Z_{ul} = Z_0 \frac{Z_2 \operatorname{ch} g + Z_0 \operatorname{sh} g}{Z_2 \operatorname{sh} g + Z_0 \operatorname{ch} g}$$

$$\Gamma_2 = \frac{Z_2 - Z_0}{Z_2 + Z_0} \qquad \Gamma_1 = \frac{Z_1 - Z_0}{Z_1 + Z_0}$$

$$|\Gamma_2| = \frac{|U_{odb}|}{|U_{pol}|}$$

$$u(x,t) = U(x)\mathrm{e}^{st}$$

$$i(x,t) = I(x)\mathrm{e}^{st}$$

$$U(x) = U(0)\operatorname{ch}\gamma x - I(0)Z_0 \operatorname{sh}\gamma x$$

$$I(x) = -U(0)\frac{\operatorname{sh}\gamma x}{Z_0} + I(0)\operatorname{ch}\gamma x$$

x - udaljenost od početka linije

γ i Z_0 - sekundarni parametri linije

$U(0)$ i $I(0)$ - napon i struja na početku linije

sinusoidalan izvor frekvencije ω_0

valna duljina λ_0: $\lambda_0 = \dfrac{2\pi}{\beta} = \dfrac{2\pi}{\omega_0\sqrt{LC}}$

$$\gamma = \sqrt{(R+j\omega L)(G+j\omega C)} = \alpha + j\beta$$

$$g = (\alpha + j\beta)l = a + jb$$

α - faktor gušenja linije po jedinici duljine

β - faktor faze linije po jedinici duljine

$$\beta = \omega\sqrt{LC}$$

$$v = \frac{\omega}{\beta} = \frac{1}{\sqrt{LC}}$$

$$g = \gamma \cdot l = \gamma \cdot k \cdot \lambda = j\omega\sqrt{LC} \cdot k \cdot \frac{2\pi}{\omega\sqrt{LC}} = j2\pi k$$

1. LINIJA BEZ GUBITAKA

$$R = G = 0$$

$$Z_0 = \sqrt{\frac{L}{C}} \qquad \gamma = s\sqrt{LC}$$

Za $s = j\omega \rightarrow$ sinusna pobuda

$$\gamma = j\omega\sqrt{LC} = j\beta \qquad \alpha = 0$$

2. LINIJA BEZ DISTORZIJE

$$RC = GL$$

$$Z_0 = \sqrt{\frac{L}{C}} \qquad \gamma = \sqrt{RG} + s\sqrt{LC}$$

Za $s = j\omega \rightarrow$ sinusna pobuda

$$\gamma = \sqrt{RC} + j\omega\sqrt{LC}$$

$$\alpha = R\sqrt{\frac{C}{L}} = \sqrt{RG} \qquad \beta = \omega\sqrt{LC}$$

$$v = \frac{\omega}{\beta} = \frac{1}{\sqrt{LC}}$$

3. RC-LINIJA

$$G = 0 \quad L = 0$$

$$Z_0 = \sqrt{\frac{R}{sC}}$$

$$Z_0 = \sqrt{\frac{R}{j\omega C}} = \sqrt{\frac{R}{\omega C}} \cdot e^{-j45^\circ}$$

$$\gamma = \sqrt{R \cdot j\omega C} = \sqrt{\omega RC}e^{j45^\circ} = \sqrt{\frac{\omega RC}{2}} + j\sqrt{\frac{\omega RC}{2}}$$

$$\alpha = \beta = \sqrt{\frac{\omega RC}{2}}$$

4. LINIJA S MALIM GUBICIMA

$$\omega L >> R \quad \omega C >> G$$

$$Z_0 = \sqrt{\frac{L}{C}} \cdot e^{-j\left(\frac{R}{2\omega L} - \frac{G}{2\omega C}\right)}$$

$$\gamma \cong \left(\frac{R}{2}\sqrt{\frac{C}{L}} + \frac{G}{2}\sqrt{\frac{L}{C}}\right) + j\omega\sqrt{LC}$$

$$\alpha = \frac{R}{2}\sqrt{\frac{C}{L}} + \frac{G}{2}\sqrt{\frac{L}{C}}$$

$$\beta = \omega\sqrt{LC}$$