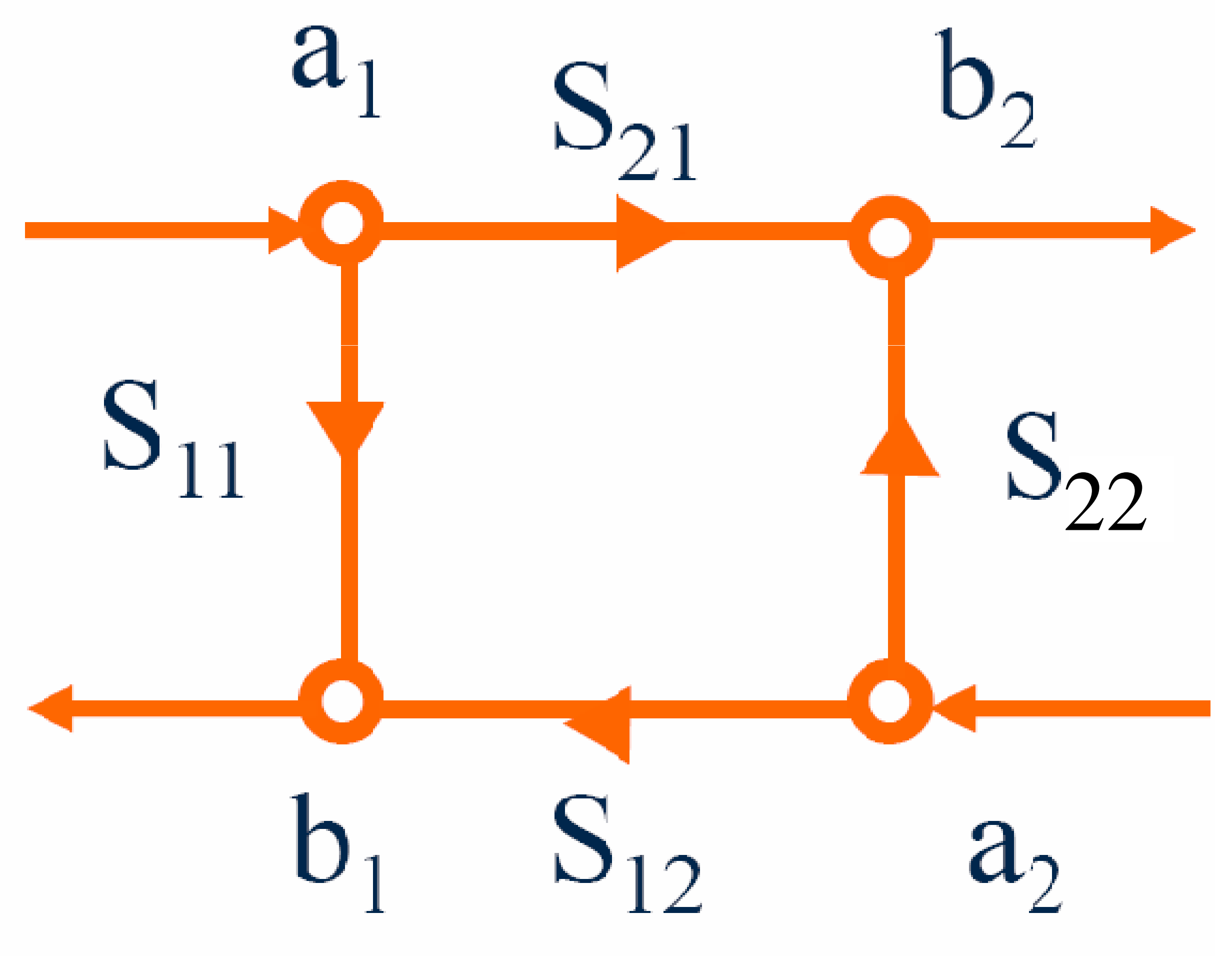
Matrika S in smerni grafi za mikrovalovno prakso



Mobitel d.d., izobraževanje

6. 11. 2009, predavanje 26

Prof. dr. Jožko Budin

Vsebina

1. Grafična predstavitev linearnih enačb s smernimi grafi:
2. Predstavitev signalnega toka 4, 6 in 8-polnih vezij z grafom
    - Primeri 4, 6, in 8- polnih vezij z grafi
3. Načini reševanja grafov:
    - Dekompozicija, redukcija
    - Masonovo pravilo nedotikajočih se zank
4. Smerni grafi običajnih in kaskadnih vezi
5. Primeri reševanja grafov

Poimenovanja in terminologija

Valovi:

Potujoči, stojni

Vpadni (napredujoči)
Povratni (odbiti)
Vhodni (vstopajoči)
Izhodni (izstopajoči)

Grafi:

Graf signalnega toka
Signalni graf oz. graf
Smerni graf

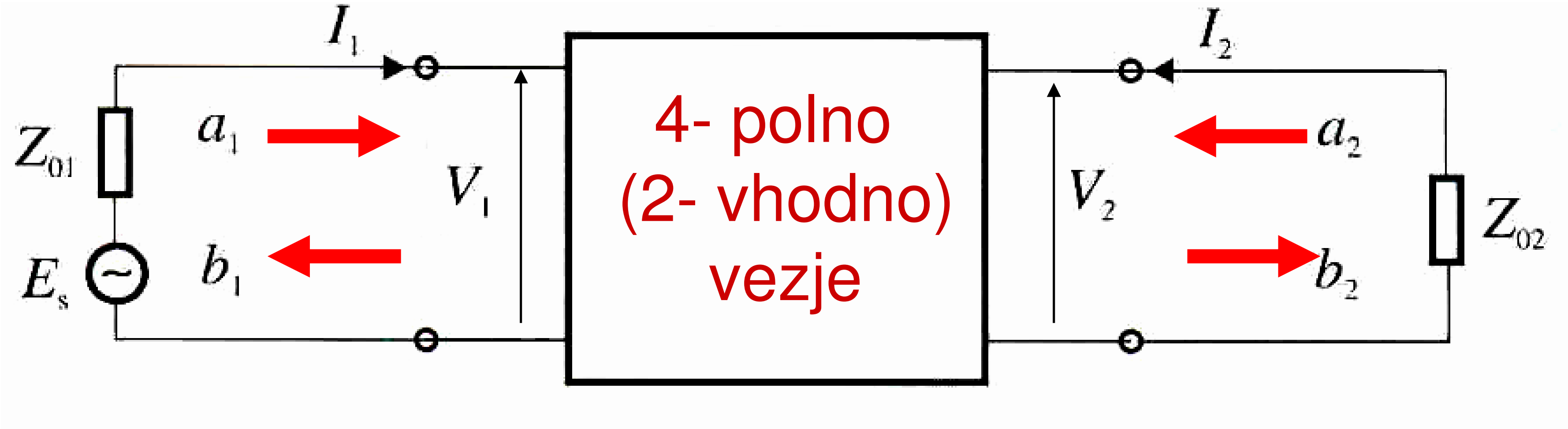
S parametri:

Matrika [S]
Matrika porazdelitve
Matrika sipanja
Matrika razpršitve

Elementi grafov:

Vir
Vozel
Zanka, red zanke
Nedotikajoča se zanka

Definicija valov



$$V_n = \sqrt{Z_{0n}}(a_n + b_n)$$

$$I_n = \frac{1}{\sqrt{Z_{0n}}}(a_n - b_n)$$

$$S_{11} = \frac{b_1}{a_1}\bigg|_{a_2=0} = \frac{V_1/\sqrt{Z_{01}} - \sqrt{Z_{01}}I_1}{V_1/\sqrt{Z_{01}} + \sqrt{Z_{01}}I_1}$$

V in I pomenita amplitudi.

Moč na n- tem vhodu:

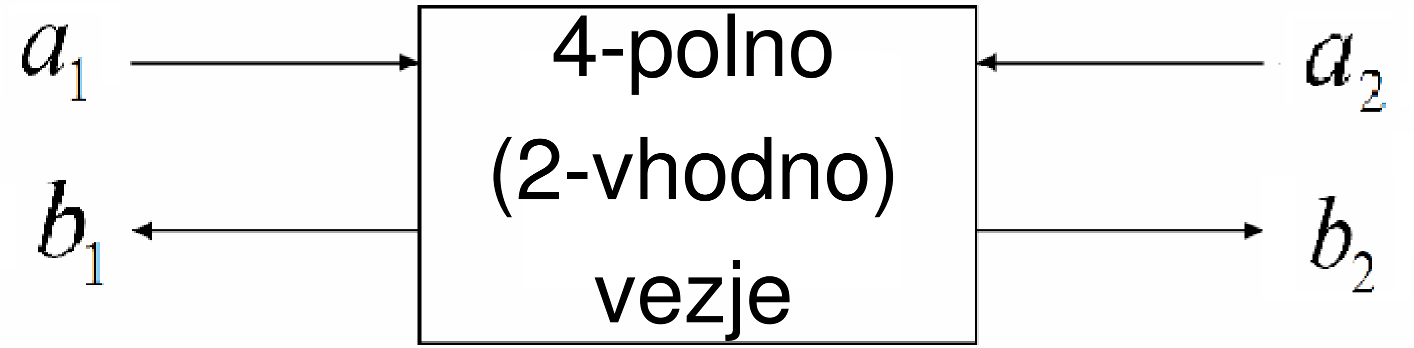
$$a_n = \frac{1}{2}\left(\frac{V_n}{\sqrt{Z_{0n}}} + \sqrt{Z_{0n}}\, I_n\right)$$

$$P_n = \tfrac{1}{2}\mathrm{Re}(V_n \cdot I_n^*) = \tfrac{1}{2}(a_n a_n^* - b_n b_n^*)$$

$$b_n = \frac{1}{2}\left(\frac{V_n}{\sqrt{Z_{0n}}} - \sqrt{Z_{0n}}\, I_n\right)$$

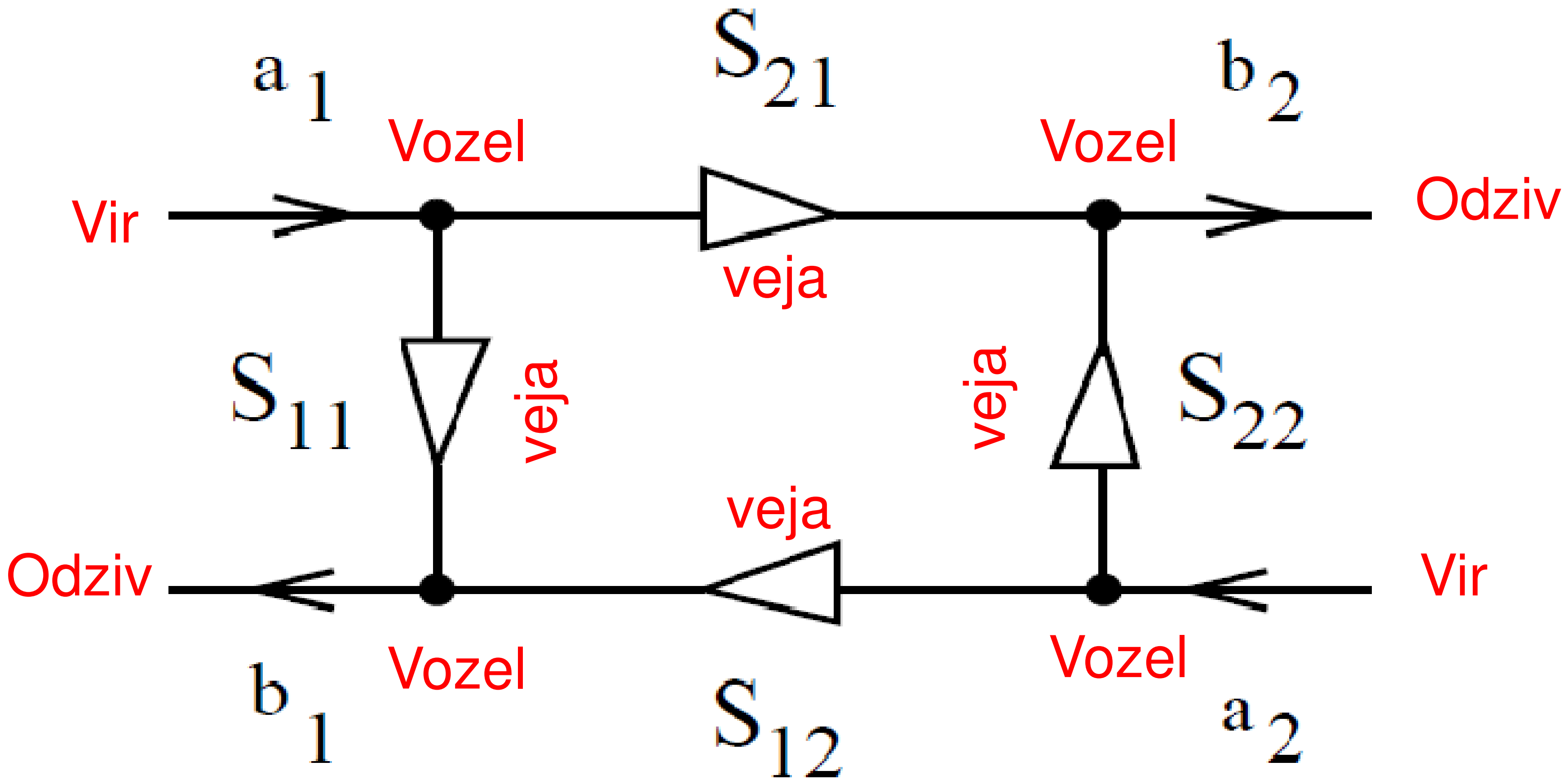
Kvadrat absolutne vrednosti potujočega vala predstavlja njegovo moč.

S-parametri 4-polnega vezja



$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

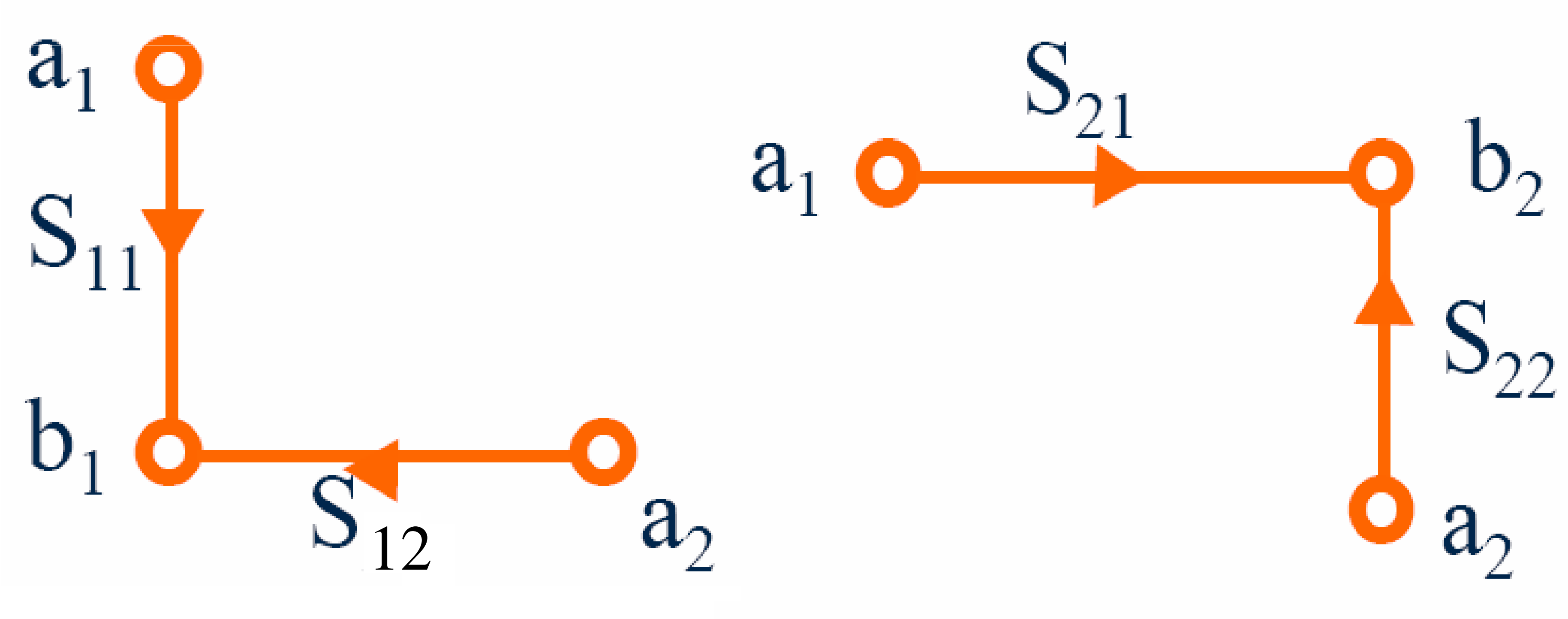
Elementi smernega grafa štiripolnega vezja



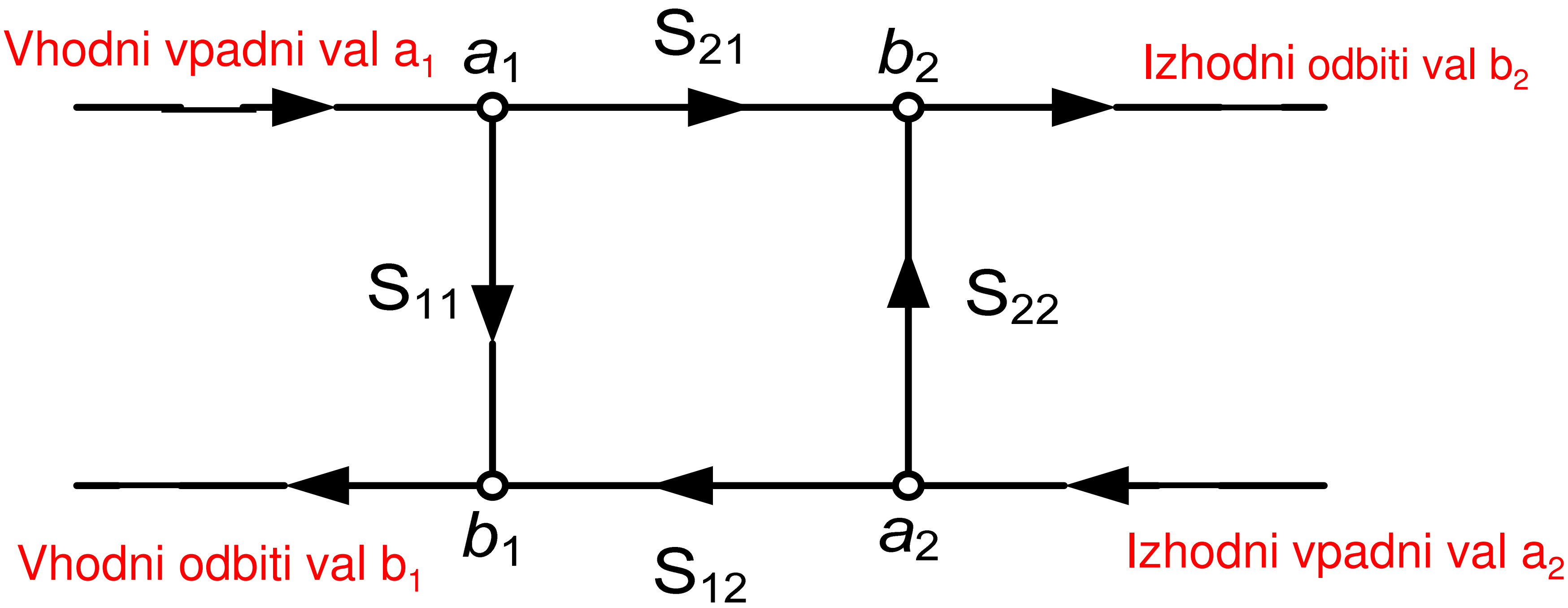
Grafična predstavitev linearnih enačb

$$b_1 = a_1 S_{11} + a_2 S_{12}$$

$$b_2 = a_1 S_{21} + a_2 S_{22}$$



4-polno vezje, graf in enačbe



$$b_1 = S_{11}a_1 + S_{12}a_2$$

$$b_2 = S_{21}a_1 + S_{22}a_2$$

Definicije parametrov matrike S

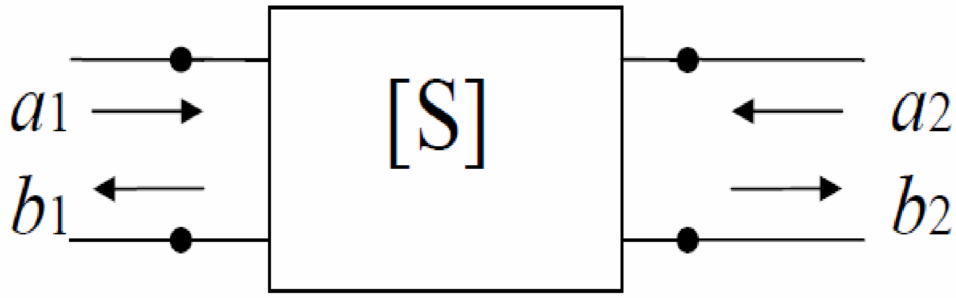
$$S_{11} = \left.\frac{b_1}{a_1}\right|_{a_2=0} = \frac{\text{odbiti val na vhodu}}{\text{vpadni val na vhodu}}$$ pri prilagojenem izhodu

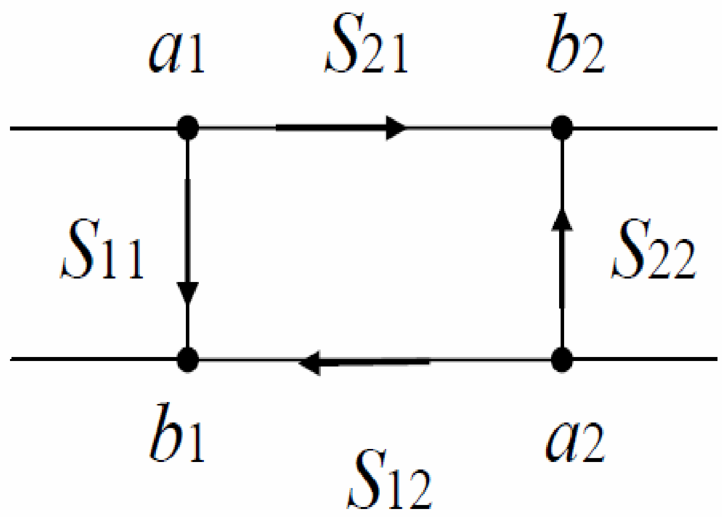
$$S_{21} = \left.\frac{b_2}{a_1}\right|_{a_2=0} = \frac{\text{odbiti (prenešeni) val na izhodu}}{\text{vpadni val na vhodu}}$$ pri prilagojenem izhodu

$$S_{22} = \left.\frac{b_2}{a_2}\right|_{a_1=0} = \frac{\text{odbiti val na izhodu}}{\text{vpadni val na izhodu}}$$ pri prilagojenem vhodu

$$S_{12} = \left.\frac{b_1}{a_2}\right|_{a_1=0} = \frac{\text{odbiti (prenešeni) val na vhodu}}{\text{vpadni val na izhodu}}$$ pri prilagojenem vhodu

4-polno vezje, graf in matrične enačbe





$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

$$b_1 = a_1 S_{11} + a_2 S_{12}$$
$$b_2 = a_1 S_{21} + a_2 S_{22}$$

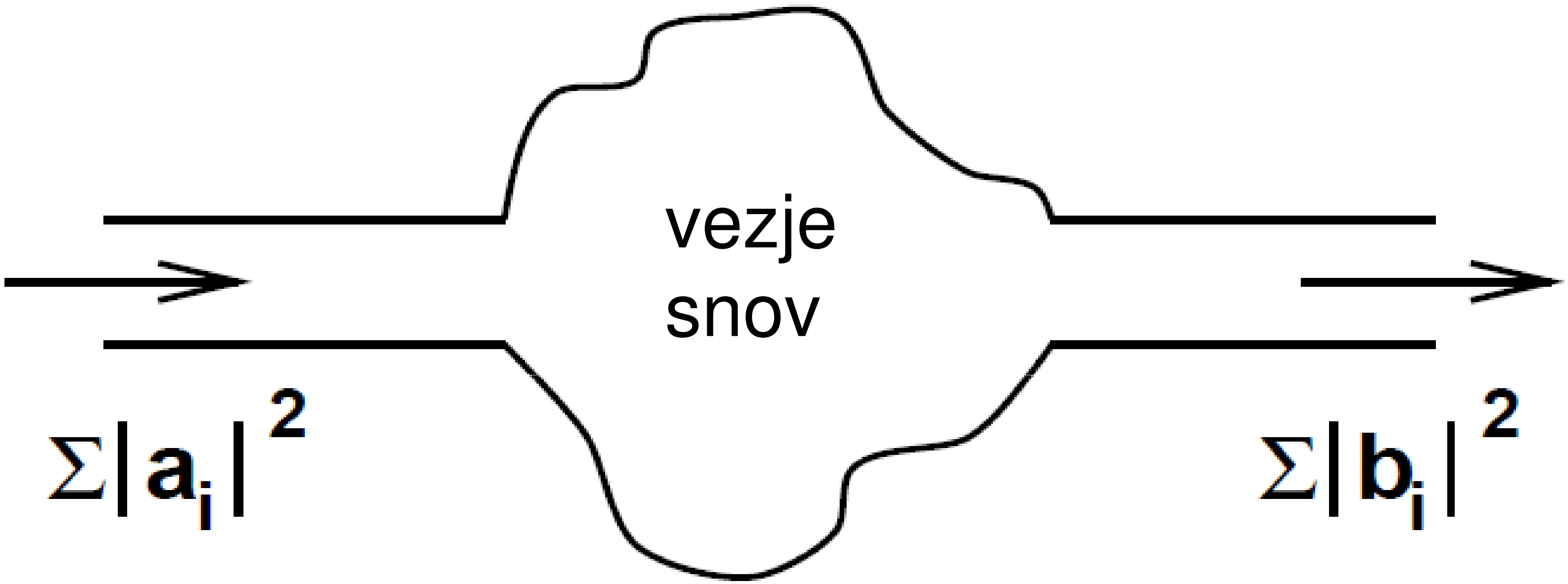
Odbojno slabljenje v dB:

$$-20\log\left|\frac{b_1}{a_1}\right| = -20\log\left|S_{11}\right|$$

Prehodno slabljenje v dB:

$$-20\log\left|\frac{b_2}{a_1}\right| = -20\log\left|S_{21}\right|$$

Vezje brez izgub

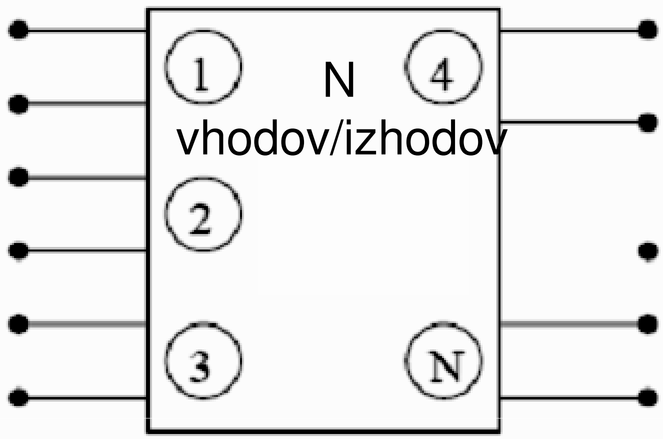


$$\sum_{i=1}^{n} |a_i|^2 = \sum_{i=1}^{n} |b_i|^2$$

Vsota moči dotekajočih valov v vezje je enaka vsoti moči odtekajočih valov iz vezja.

Temeljne lastnosti vezij in matrike [S]

2N-polno vezje:



Matrika [S] 2N-polnega vezja:

$$\begin{bmatrix} S_{11} & S_{12} & S_{13} & \bullet & S_{1N} \\ S_{21} & S_{22} & S_{23} & \bullet & S_{2N} \\ S_{31} & S_{32} & S_{33} & \bullet & \bullet \\ \bullet & \bullet & \bullet & \bullet & \bullet \\ S_{N1} & S_{N2} & \bullet & \bullet & S_{NN} \end{bmatrix}$$

Definicija:

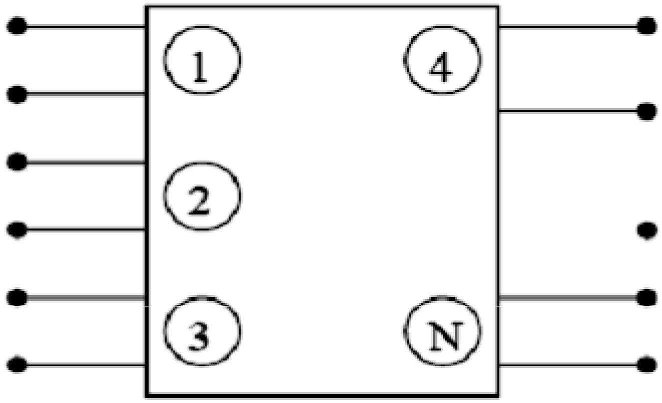
$$S_{ij} = \left. \frac{V_i^-}{V_j^+} \right|_{V_k^+=0,\, k \neq j}$$

Temeljne lastnosti vezja in lastnosti matrike:

1. Notranja prilagojenost: $S_{ii} = 0;$
2. Recipročnost: $[S] = [S]^T, \; ali \; S_{ij} = S_{ji}$
3. Brezizgubnost (unitarnost): $([S]^*)^T \, [S] = [1],$
4. Brezizgubnost in recipročnost: $[S]^* = [S]^{-1}$

Splošne lastnosti matrike [S] N-polnega vezja

N-polno vezje:



Matrika S N-polnega vezja:

$$\begin{bmatrix} S_{11} & S_{12} & S_{13} & \bullet & S_{1N} \\ S_{21} & S_{22} & S_{23} & \bullet & S_{2N} \\ S_{31} & S_{32} & S_{33} & \bullet & \bullet \\ \bullet & \bullet & \bullet & \bullet & \bullet \\ S_{N1} & S_{N2} & \bullet & \bullet & S_{NN} \end{bmatrix}$$

Definicija:

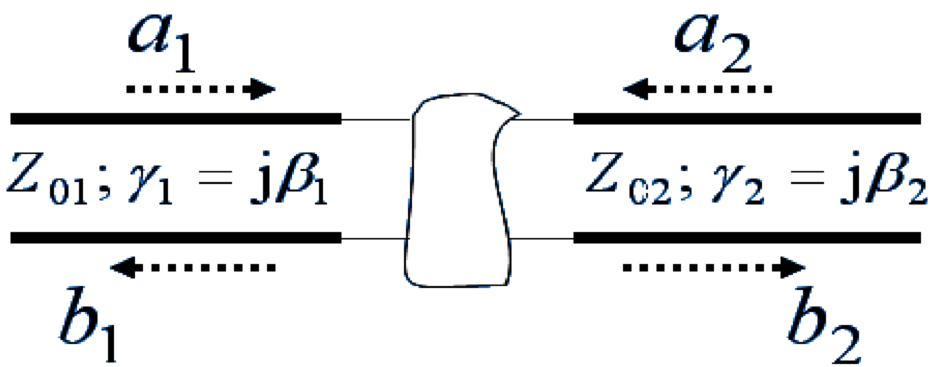
$$S_{ij} = \left. \frac{V_i^-}{V_j^+} \right|_{V_k^+=0,\, k\neq j}$$

Lastnosti vezja in matrike:

1. Notranja prilagojenost — $S_{ii} = 0$
2. Recipročnost — $S_{ij} = S_{ji}$
3. Brezizgubnost — $S\, S^{*T} = 1$ unitarnost

4-polno recipročno vezje brez izgub

$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \cdot \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$



Linearno recipročno vezje $\quad S_{12} = S_{21}$

Dvopolno vezje brez izgub $\quad S = \Gamma = e^{j\phi} \rightarrow S \cdot S^* = 1$

Štiripolno vezje brez izgub

$$\begin{bmatrix} S_{11} & S_{12} \\ S_{12} & S_{22} \end{bmatrix} \cdot \begin{bmatrix} S_{11}^* & S_{12}^* \\ S_{12}^* & S_{22}^* \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

$\mathbf{S} \cdot \mathbf{S}^* = \mathbf{1}$ $\quad \mathbf{S}$ unitarna matrika

$$S_{11}S_{11}^* + S_{12}S_{12}^* = 1 \rightarrow |S_{11}|^2 + |S_{12}|^2 = 1$$

$$S_{11}S_{12}^* + S_{12}S_{22}^* = 0 \rightarrow e^{j(\phi_{11}-\phi_{12})} + e^{j(\phi_{12}-\phi_{22})} = 0$$

$$S_{12}S_{11}^* + S_{22}S_{12}^* = 0$$

$$S_{12}S_{12}^* + S_{22}S_{22}^* = 1 \rightarrow |S_{12}|^2 + |S_{22}|^2 = 1$$

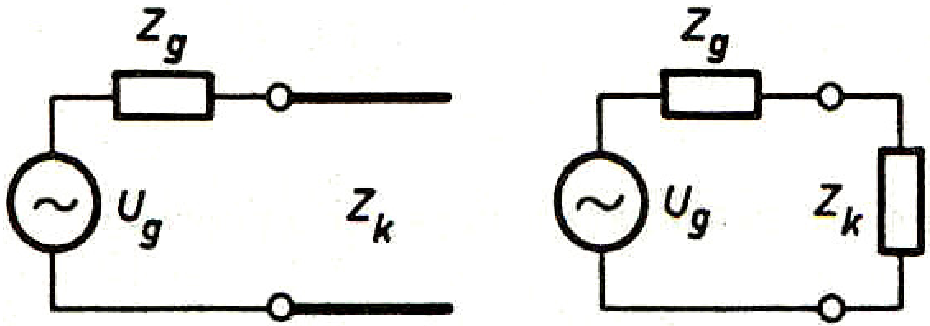
$$|S_{11}| = |S_{22}| = \sqrt{1 - |S_{12}|^2}$$

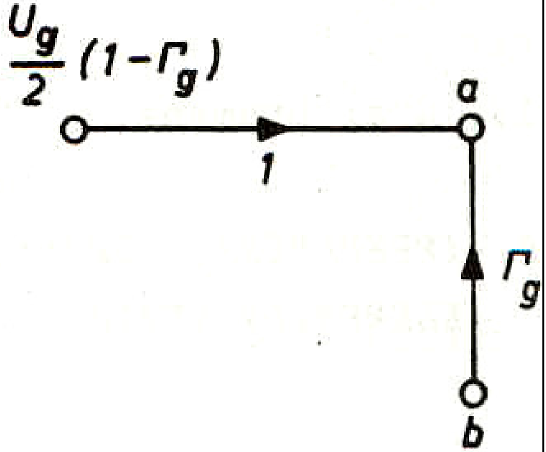
$$|S_{11}| = |S_{22}| = 0 \rightarrow |S_{12}| = 1$$

$$|S_{11}| = |S_{22}| \neq 0 \rightarrow \phi_{11} + \phi_{22} - 2\phi_{12} = \pi$$

Smerni graf generatorja in bremena

Graf generatorja

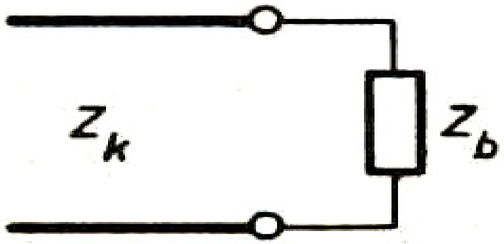


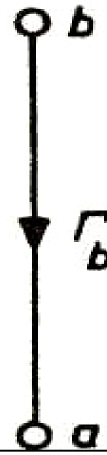


$$a = U_g \frac{Z_k}{Z_g + Z_k} = \frac{U_g}{2}(1 - \Gamma_g)$$

$$a = \Gamma_g b = \frac{Z_g - Z_k}{Z_g + Z_k} b$$

Graf bremena

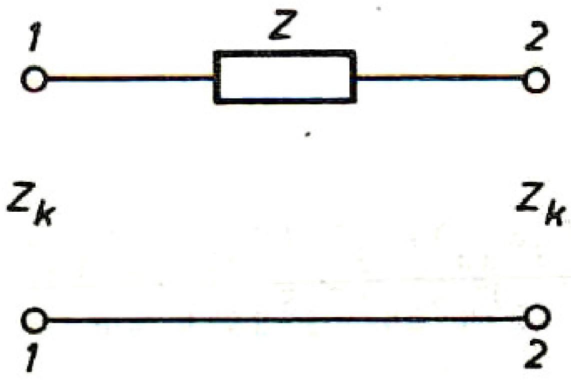


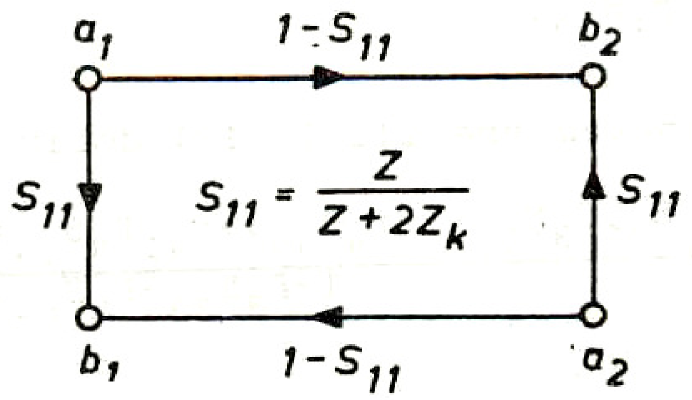


$$\Gamma_b = \frac{Z_b - Z_k}{Z_b + Z_k}$$

Graf zaporedne impedance in vzporedne admitance

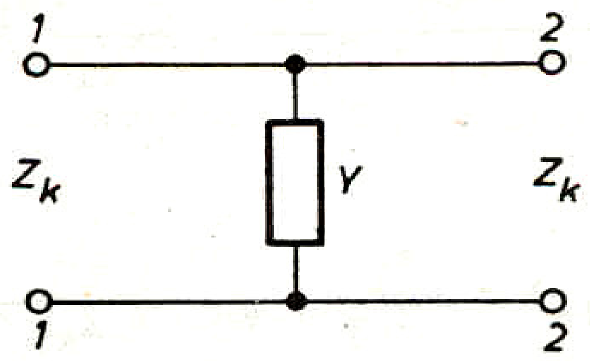
Zaporedna impedanca na liniji karakteristične impedance Z_k

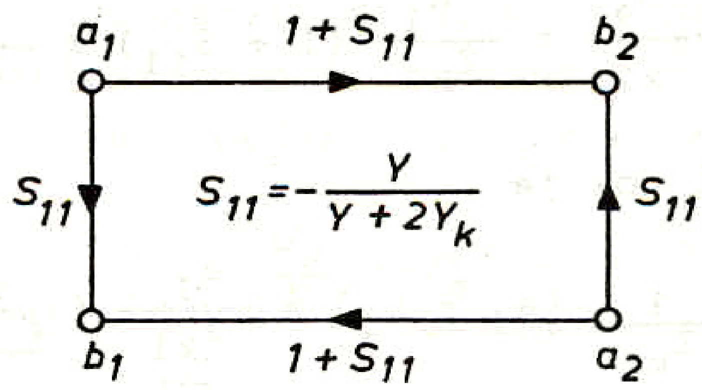




$$S_{11} = \frac{(Z + Z_k) - Z_k}{(Z + Z_k) + Z_k} = \frac{Z}{Z + 2Z_k}$$

Vzporedna admitanca na liniji karakteristične impedance Z_k

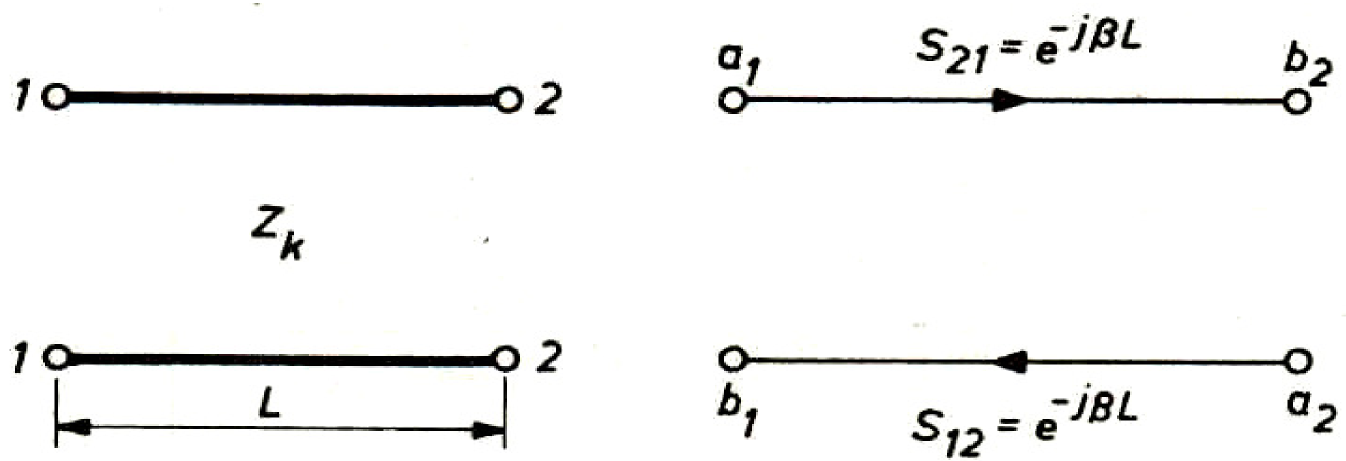




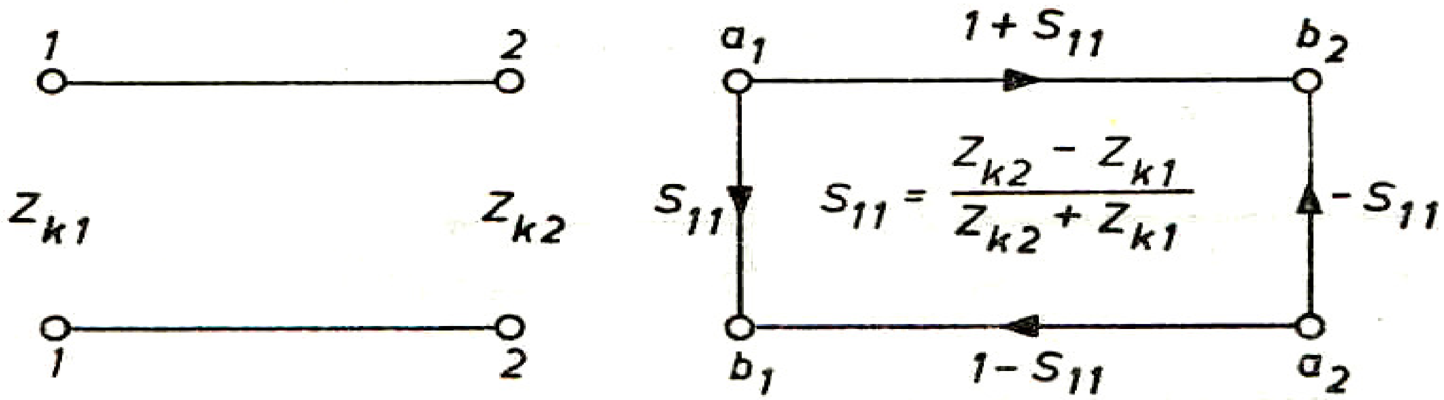
$$S_{11} = \frac{Y_k - (Y + Y_k)}{Y_k + (Y + Y_k)} = - \frac{Y}{Y + 2Y_k}$$

Graf odseka linije in preskoka karakt. impedance

Odsek
homogene
linije

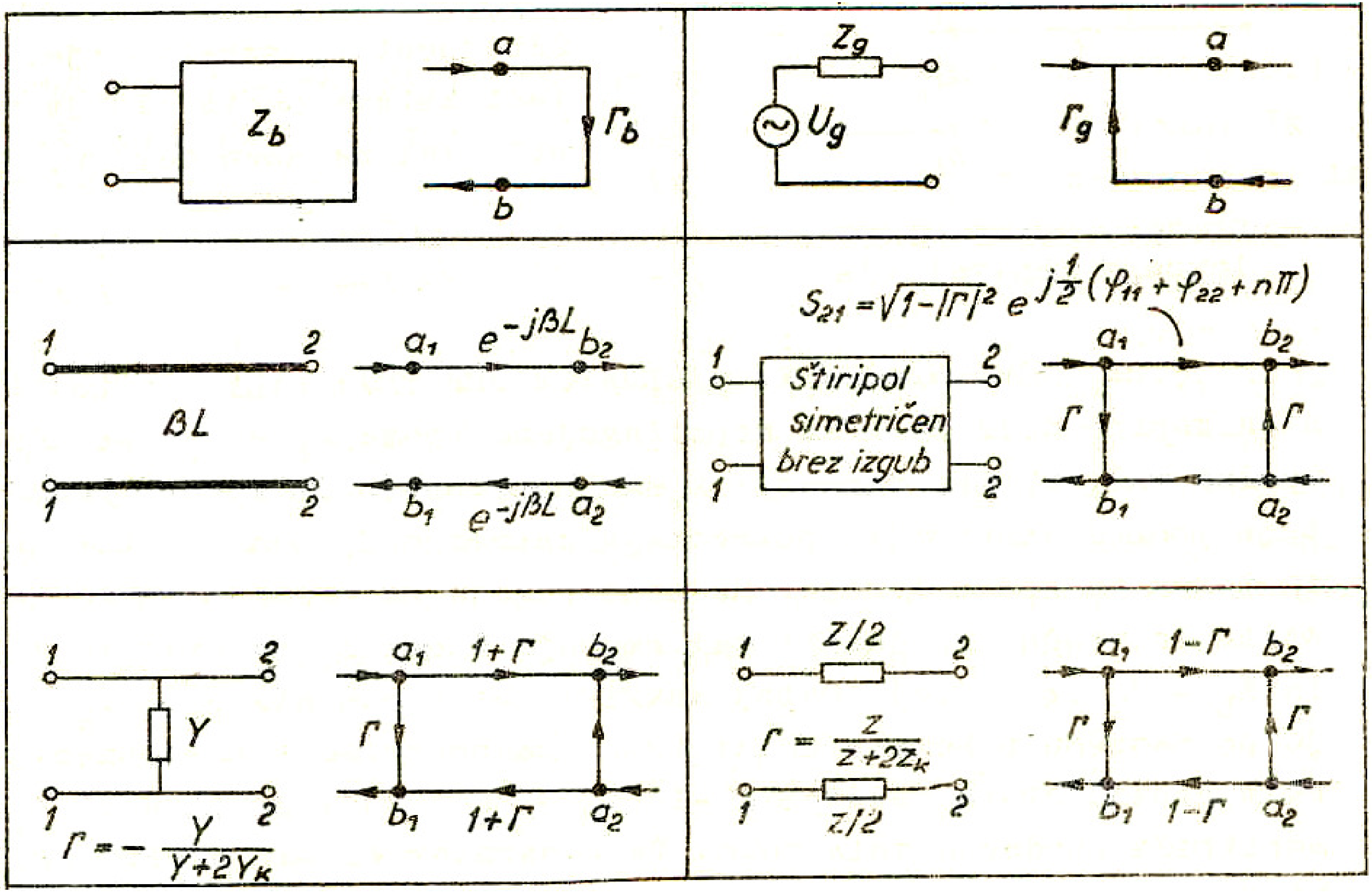


Preskok
karakteristične
impedance

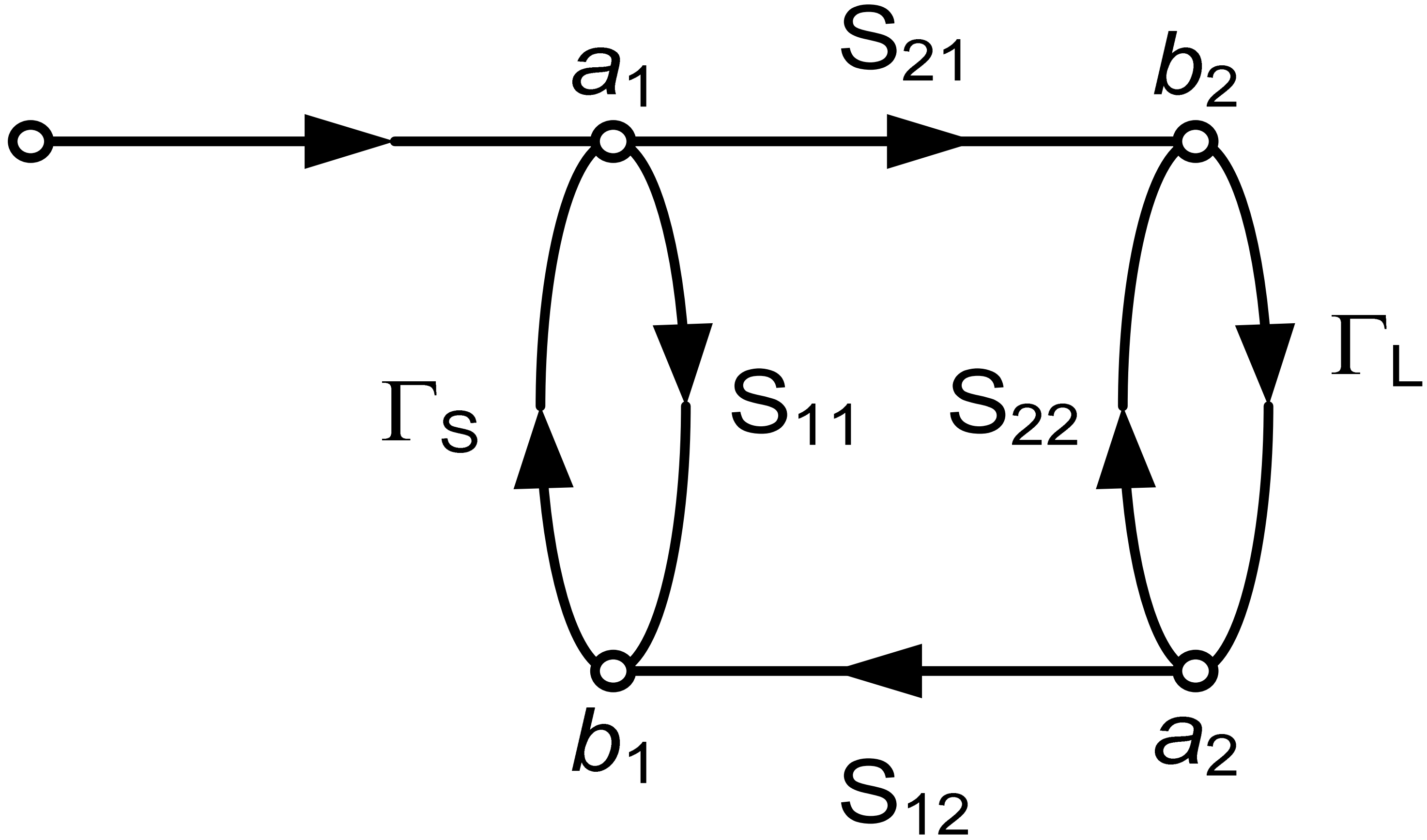


Napetost in tok prehajata zvezno.

Smerni grafi osnovnih gradnikov, pregled



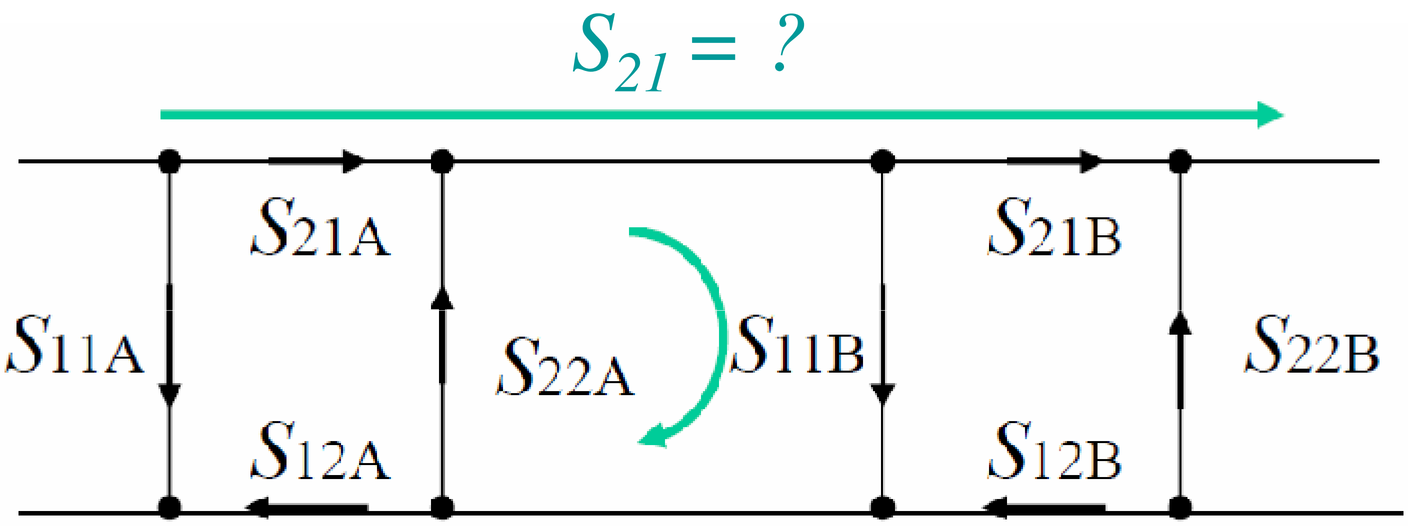
Smerni graf generatorja, vezja in bremena



Na stiku generatorja z vezjem se pojavlja zanka s koeficientom $\Gamma_s S_{11.}$ Na stiku vezja in bremena se pojavlja druga zanka s koeficientom $S_{22}\ \Gamma_L$.

Kaskadna vezava četveropolov

Četveropola A in B, vezana v verigo, sestavljata na stiku odbojno zanko, ki povzroča povratni sklop.



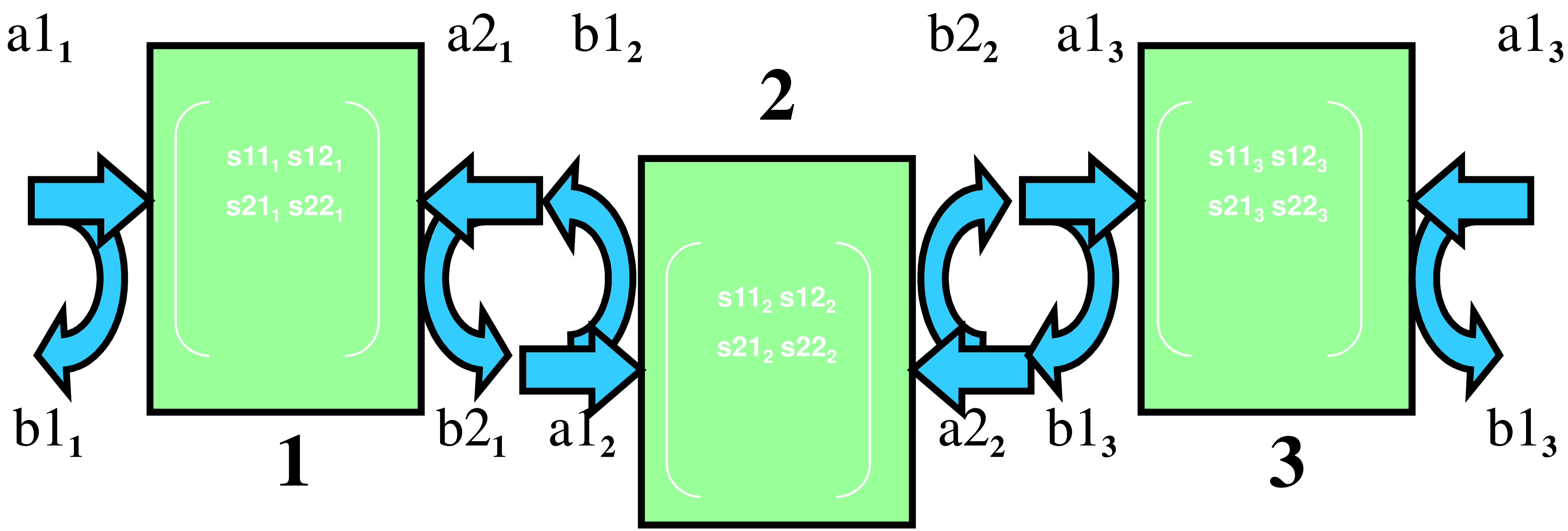
Povratni sklop: odvisnost 1/(1-k)

$$S_{21} = \frac{S_{21}^{A} S_{21}^{B}}{1 - S_{22}^{A} S_{11}^{B}}$$

Koeficient povratnega sklopa:

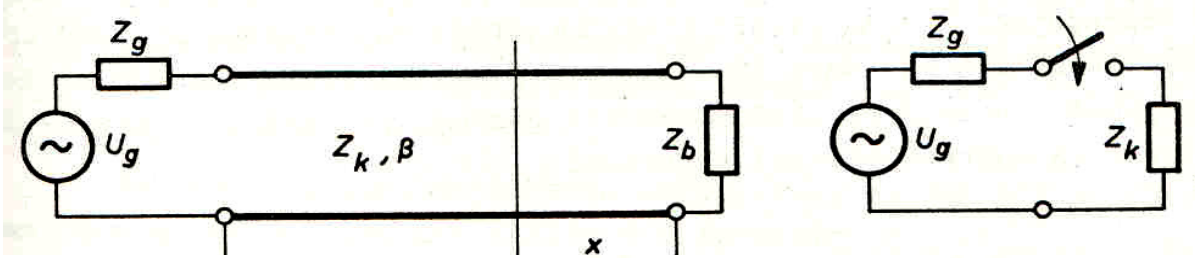
$k = S_{22}^{A} S_{11}^{B}$

Povratne zanke na verigi četveropolov

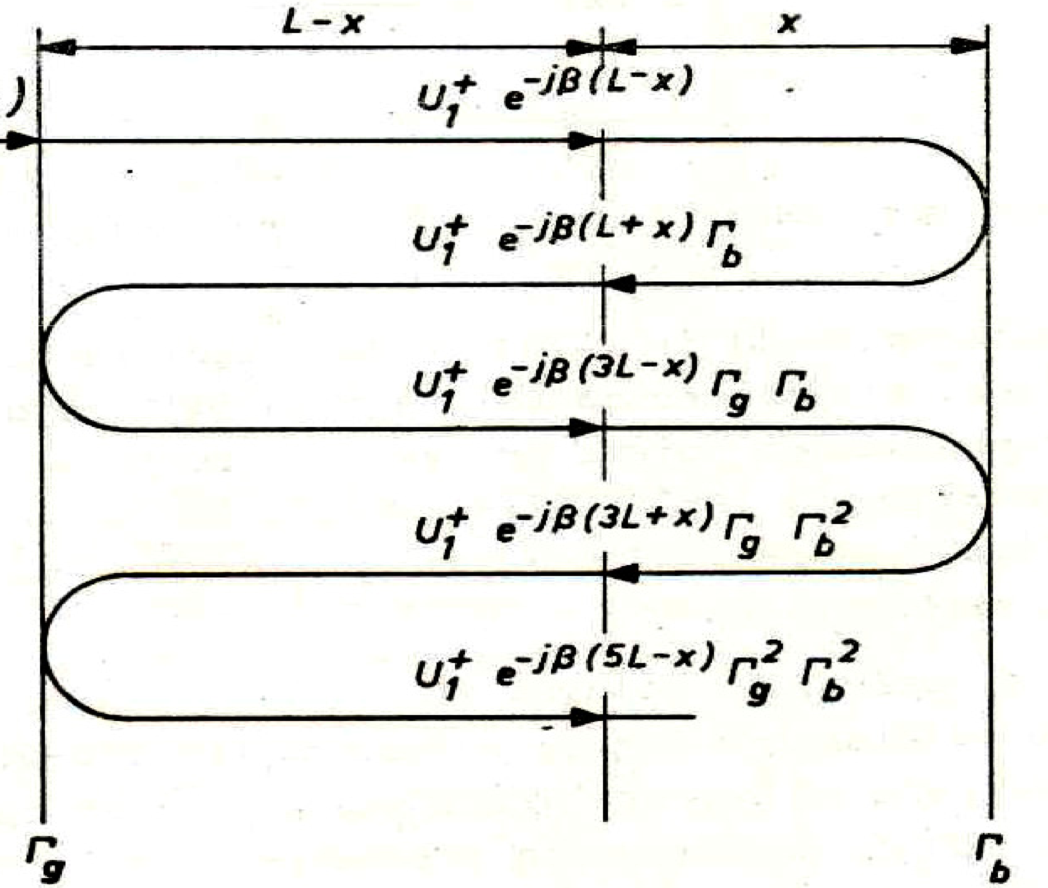


Slika prikazuje tipični valovni pojav, ki nastaja na kaskadni vezavi četveropolov. Vezje obravnavamo z valovno matriko [S]. Za predstavitev problemov in izpeljavo formul uporabljamo smerne grafe zaradi preglednosti in predstavljivosti valovnih pojavov.

Valovni pojavi na liniji, valovna obravnava



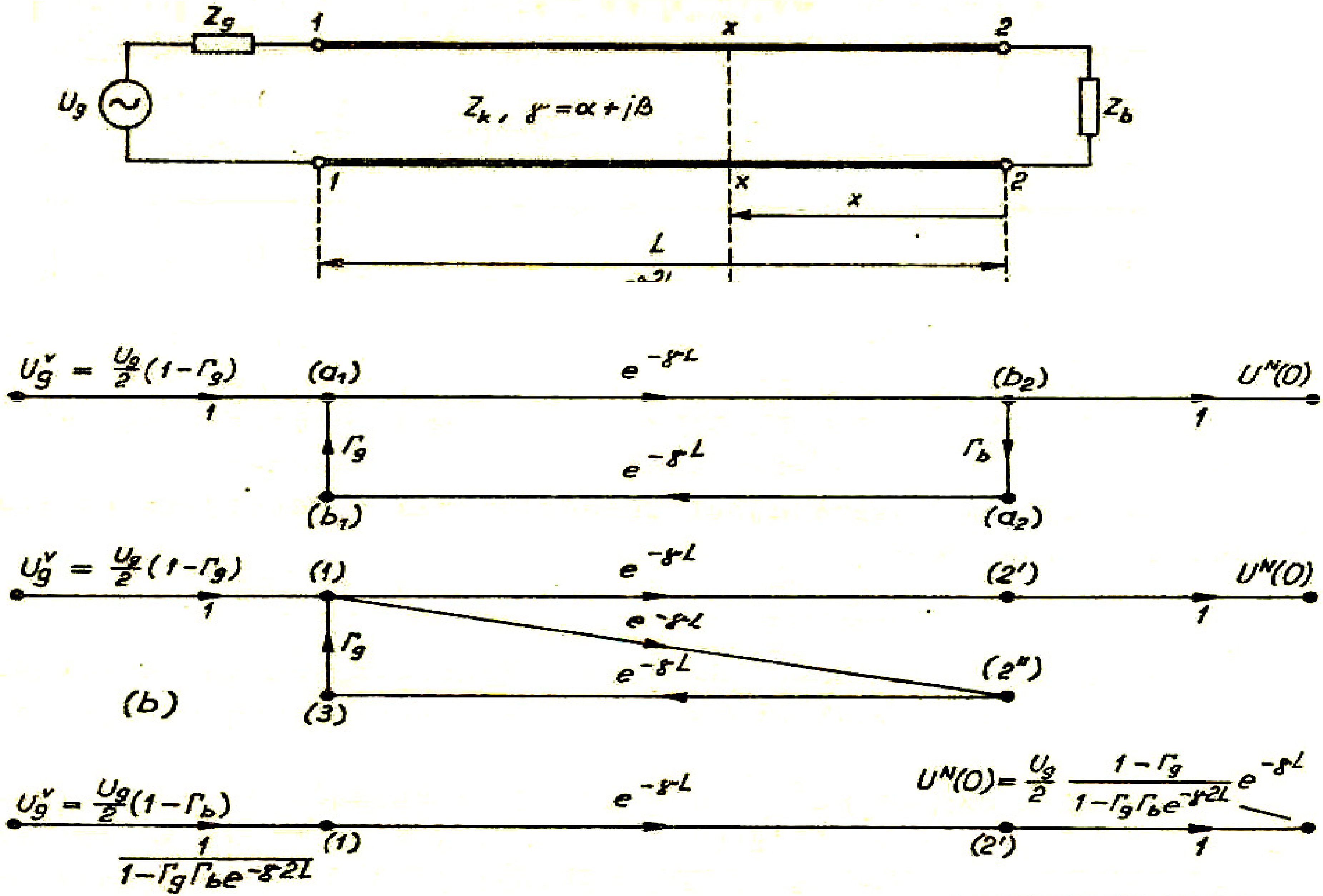
$$U_1^+ = \frac{U_g}{2}(1-\Gamma_g)$$



$$U^+(x) = U_1^+ e^{-j\beta(L-x)}\,(1 + \Gamma_g\Gamma_b e^{-j\beta 2L} + \Gamma_g^2\Gamma_b^2\, e^{-j\beta 4L} + \dots)$$

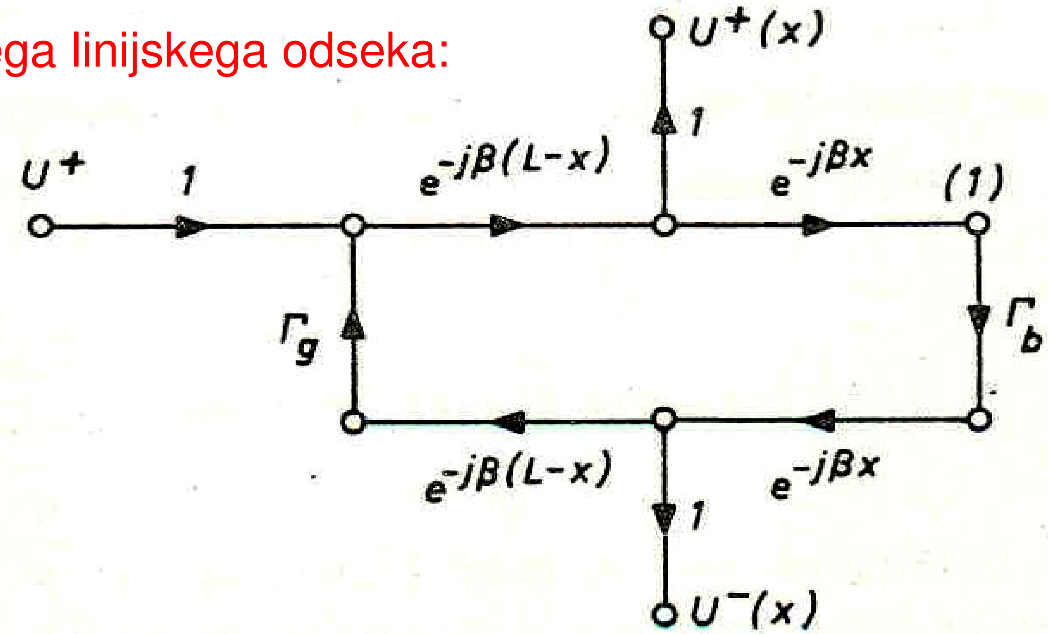
$$U^+(x) = U_1^+ \frac{e^{-j\beta(L-x)}}{1 - \Gamma_g\Gamma_b e^{-j\beta 2L}}$$

Smerni graf napredujočega vala na liniji



Valovni pojavi na liniji, obravnava z grafom

Graf obremenjenega linijskega odseka:



Napredujoči val:

$$U^+(x) = \frac{U_g}{2}(1-\Gamma_g)\frac{e^{-j\beta(L-x)}}{1-\Gamma_g\Gamma_b e^{-j\beta 2L}}$$

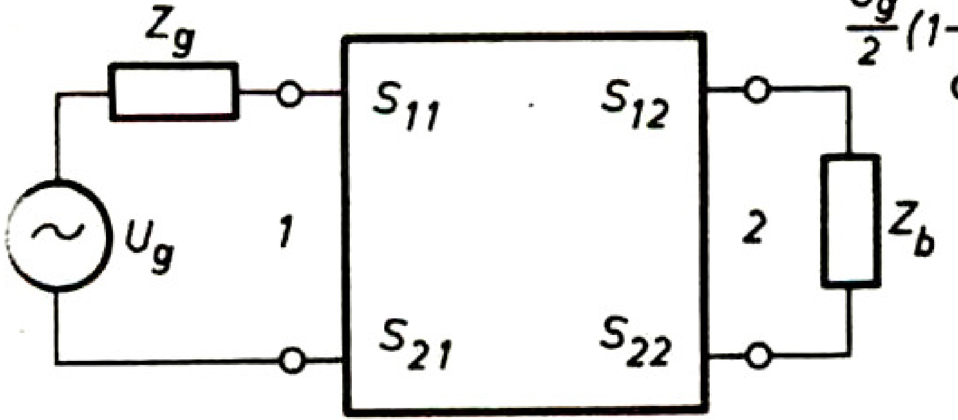
Odbiti val:

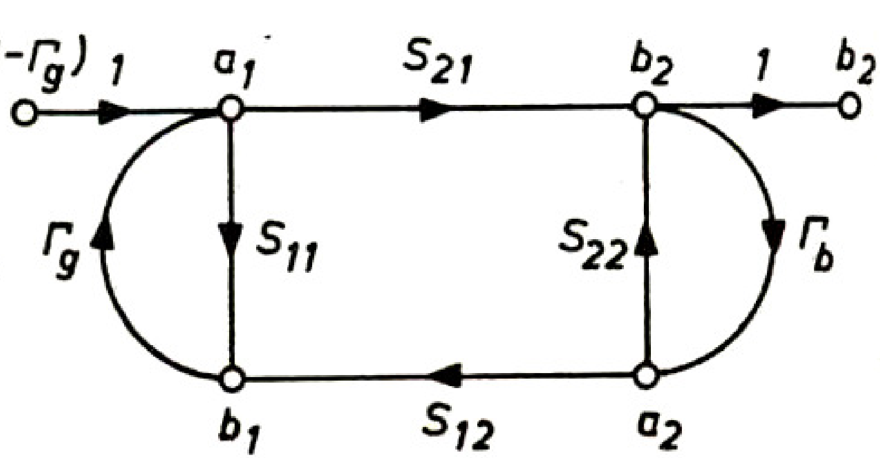
$$U^-(x) = \frac{U_g}{2}(1-\Gamma_g)\frac{e^{-j\beta(L+x)}}{1-\Gamma_g\Gamma_b e^{-j\beta 2L}}\Gamma_b$$

Stojni val:

$$U(x) = U^+(x) + U^-(x) = \frac{U_g}{2}(1-\Gamma_g)\frac{e^{-j\beta(L-x)}}{1-\Gamma_g\Gamma_b e^{-j\beta 2L}}(1+\Gamma_b e^{-j\beta 2x}).$$

Slabljenje štiripolnega vezja



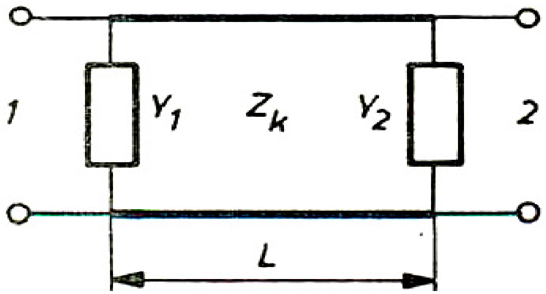


$$b_2 = \frac{U_g}{2}(1 - \Gamma_g)\frac{S_{21}}{(1 - \Gamma_g S_{11})(1 - \Gamma_b S_{22}) - \Gamma_g \Gamma_b S_{21} S_{12}}$$

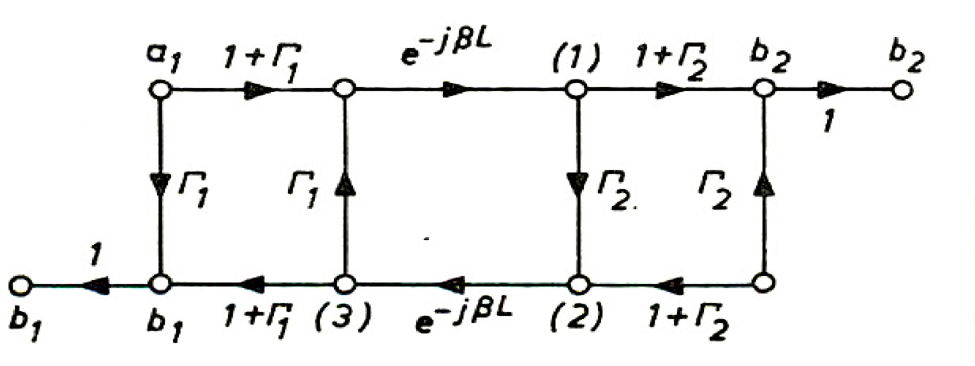
Slabljenje $L = 20 \log |b_2/a_1|$ je enako $20 \log |S_{21}|$ v primeru, ko sta vhod in izhod vezja prilagojena ($\Gamma_g = \Gamma_b = 0$)

Vzporedni admitanci na linijskem odseku

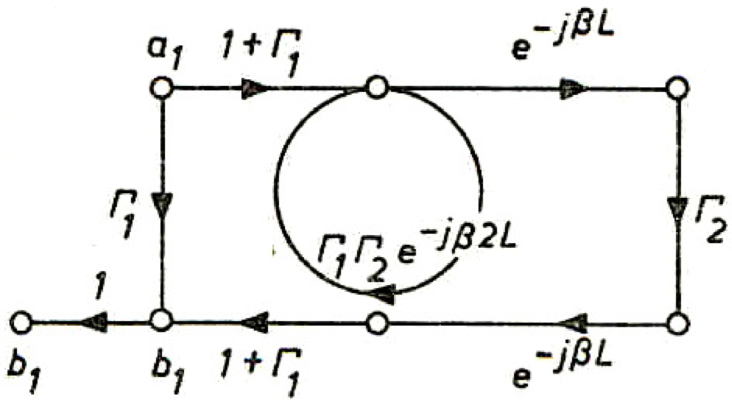
Vezje:

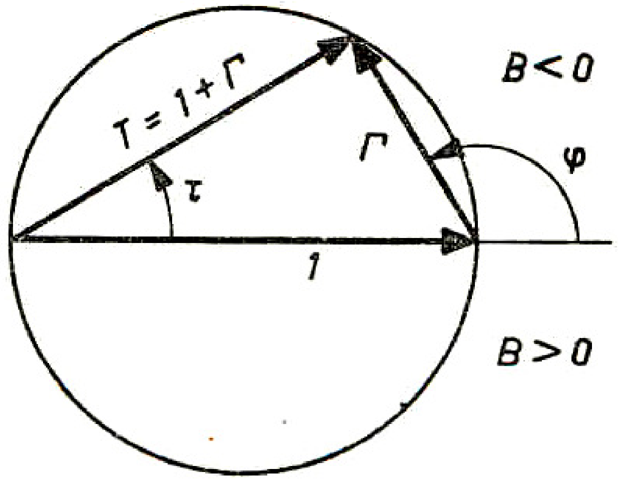


Smerni graf:



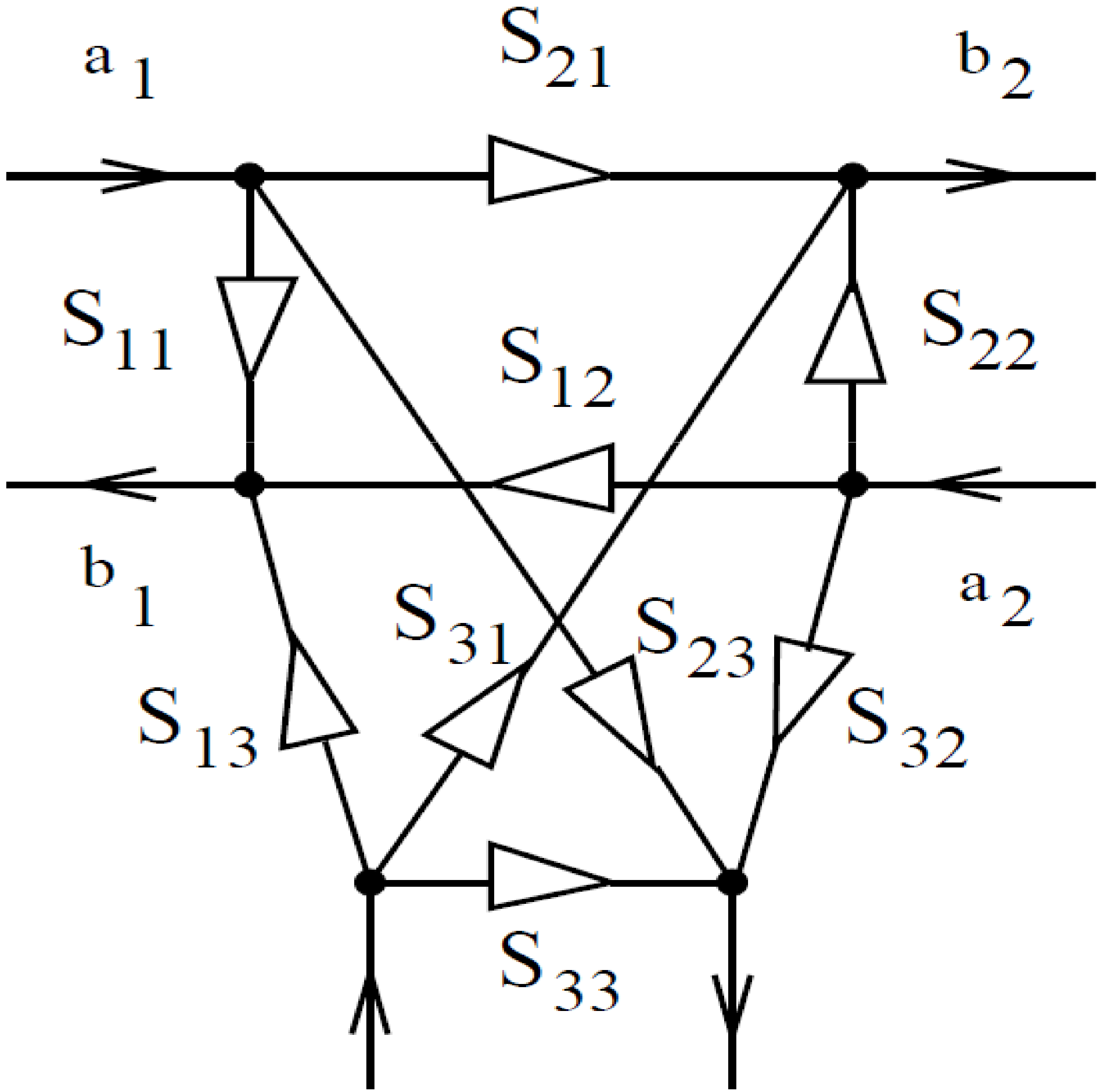
Reduciran smerni graf:





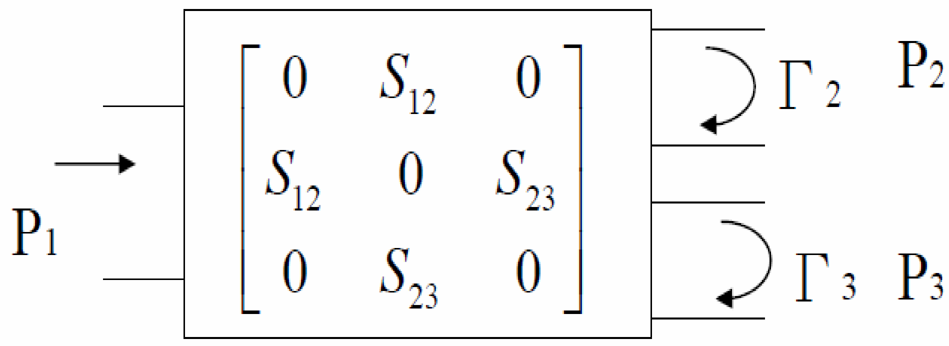
$$S_{11} = \frac{b_1}{a_1} = \Gamma_1 + \frac{(1+\Gamma_1)^2 \Gamma_2 e^{-j\beta 2L}}{1 - \Gamma_1 \Gamma_2 e^{-j\beta 2L}} \qquad S_{21} = \frac{b_2}{a_1} = \frac{(1+\Gamma_1)(1+\Gamma_2) e^{-j\beta L}}{1 - \Gamma_1 \Gamma_2 e^{-j\beta 2L}} .$$

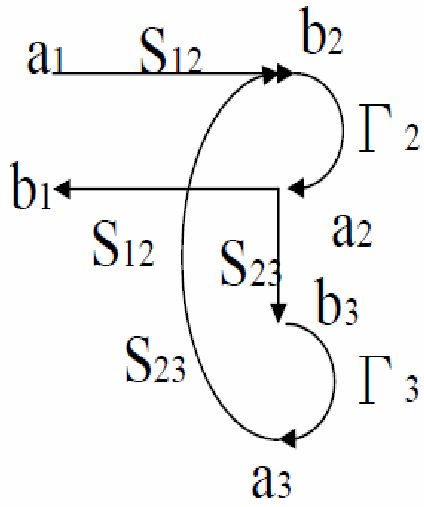
Smerni graf šestpolnega vezja



Primer 6-polnega vezja

6-polno recipročno notranje prilagojeno vezje





$$b_1 = a_1 \frac{S_{12}^2 \Gamma_2}{1-\Gamma_2\Gamma_3 S_{23}^2}, b_2 = a_1 \frac{S_{12}}{1-\Gamma_2\Gamma_3 S_{23}^2}, b_3 = a_1 \frac{S_{12}\Gamma_2 S_{23}}{1-\Gamma_2\Gamma_3 S_{23}^2}$$

$$\frac{P_2}{P_1} = \frac{|b_2|^2 - |a_2|^2}{|a_1|^2 - |b_1|^2} = \frac{|b_2|^2(1-|\Gamma_2|^2)}{|a_1|^2(1-|\Gamma_{in}|^2)} = \frac{|S_{12}|^2(1-|\Gamma_2|^2)}{|1-\Gamma_2\Gamma_3 S_{23}^2|^2\left(1-\frac{|S_{12}^2\Gamma_2|^2}{|1-\Gamma_2\Gamma_3 S_{23}^2|^2}\right)} = \frac{|S_{12}|^2(1-|\Gamma_2|^2)}{|1-\Gamma_2\Gamma_3 S_{23}^2|^2 - |S_{12}^2\Gamma_2|^2}$$

$$\frac{P_3}{P_1} = \frac{|b_3|^2 - |a_3|^2}{|a_1|^2 - |b_1|^2} = \frac{|b_3|^2(1-|\Gamma_3|^2)}{|a_1|^2(1-|\Gamma_{in}|^2)} = \frac{|S_{12}|^2|\Gamma_2|^2|S_{23}|^2(1-|\Gamma_3|^2)}{|1-\Gamma_2\Gamma_3 S_{23}^2|^2\left(1-\frac{|S_{12}^2\Gamma_2|^2}{|1-\Gamma_2\Gamma_3 S_{23}^2|^2}\right)} = \frac{|S_{12}|^2|\Gamma_2|^2|S_{23}|^2(1-|\Gamma_2|^2)}{|1-\Gamma_2\Gamma_3 S_{23}^2|^2 - |S_{12}^2\Gamma_2|^2}$$

Obravnava smernih grafov

1. Elementi grafov
- vozli
- veje
- zanke

2. Pravila dekompozicije (redukcije) grafov
- adicija
- multiplikacija
- pravilo povratne zanke
- distribucija

3. Masonovo pravilo nedotikajočih se zank

Smerni graf in njegovi elementi

Sistem linearnih enačb:

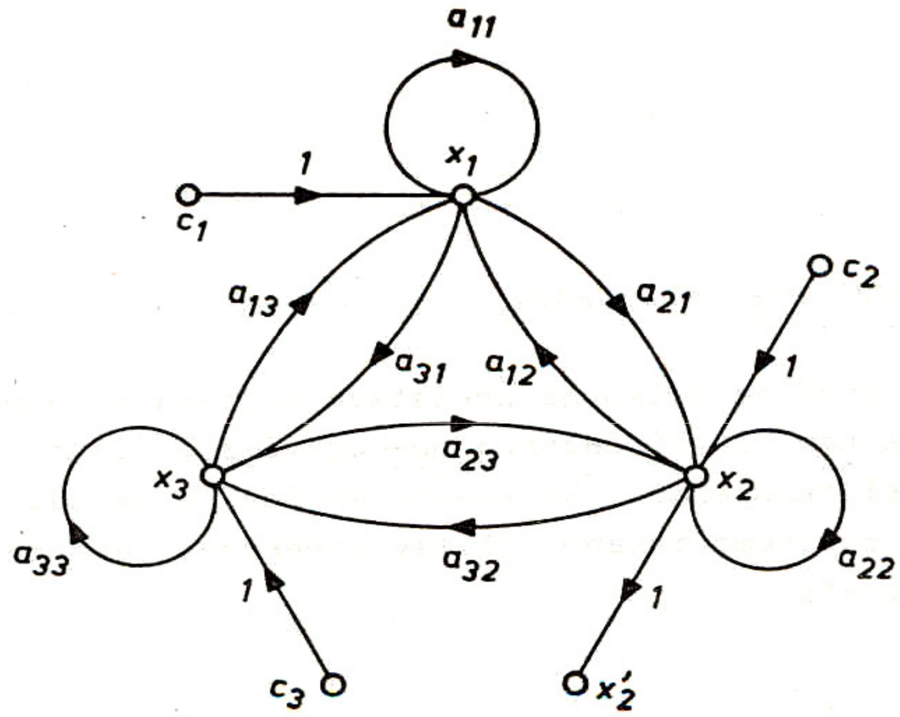
$$a_{11}x_1 + a_{12}x_2 + a_{13}x_3 + c_1 = x_1$$

$$a_{21}x_1 + a_{22}x_2 + a_{23}x_3 + c_2 = x_2$$

$$a_{31}x_1 + a_{32}x_2 + a_{31}x_3 + c_3 = x_3$$

x_1, x_2, x_3 ... spremenljivke
a_{11}, a_{12} do a_{33} ... koeficienti
c_1, c_2, c_3 ... konstante

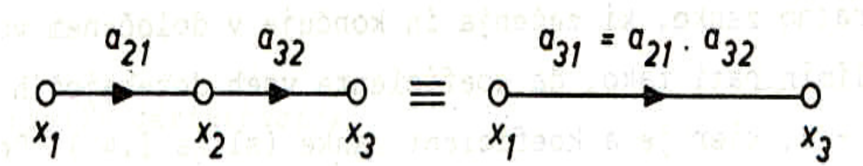
Smerni graf



x_1, x_2, x_3 ... vozli smernega grafa
a_{11}, a_{12} do a_{33} ... koeficienti vej
c_1, c_2, c_3 ... viri smernega grafa

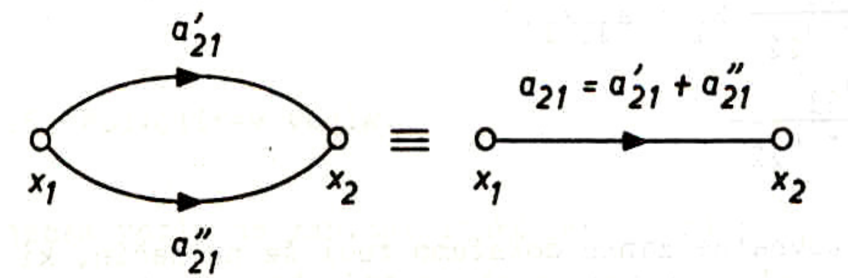
Pravila redukcije smernega grafa

1. Multiplikacija



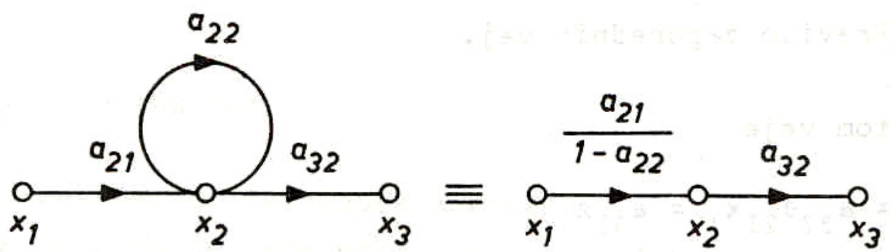
Koeficienti zaporednih vej se množijo.

2. Adicija



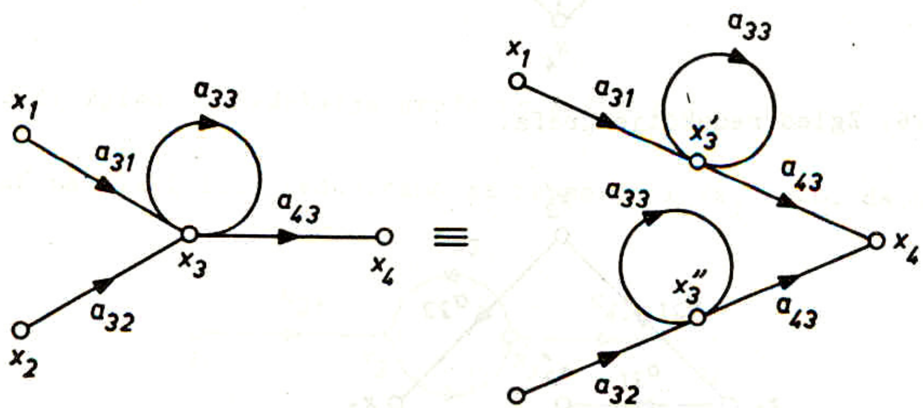
Koeficienti vzporednih vej se seštevajo.

3. Pravilo povratne zanke



Povratno zanko eliminiramo tako, da koeficient predhodne veje množimo z $1/(1 - a_{22})$, ki je vsota geometrijske vrste.

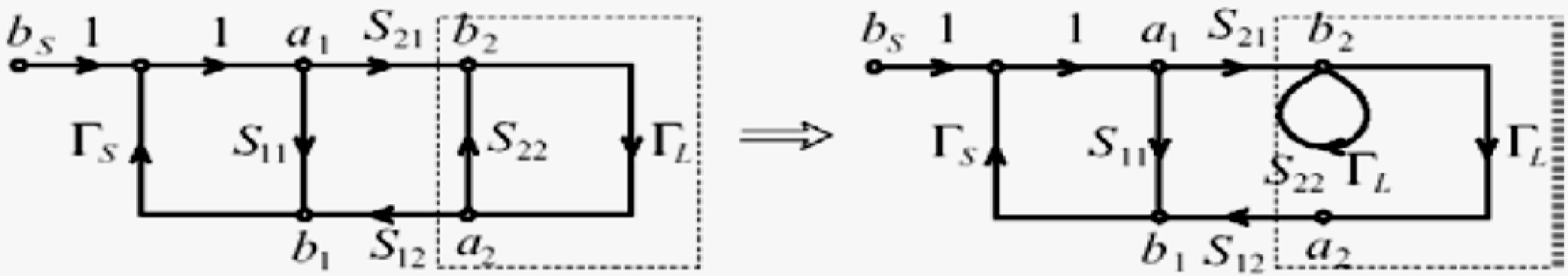
4. Distribucija



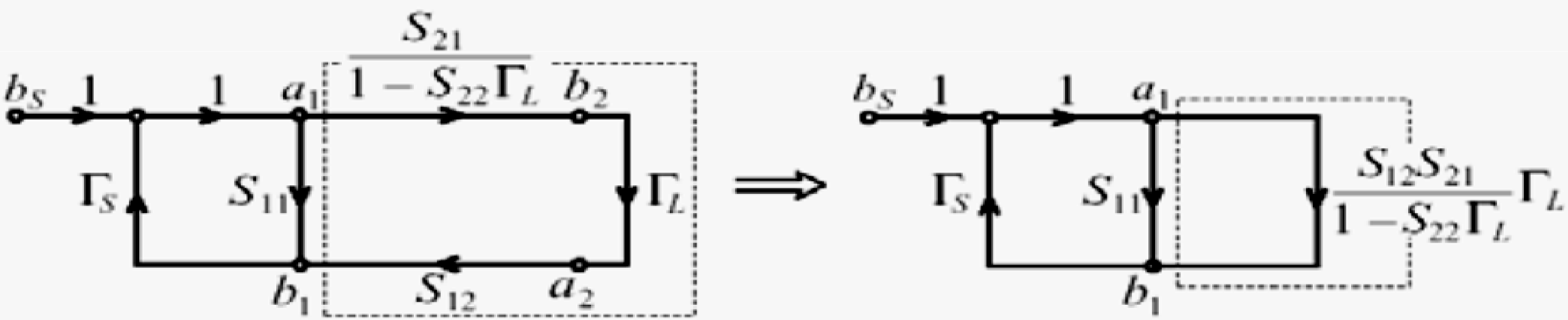
Vozel s povratno zanko dveh ali več dotekajočih vej podvojimo.

Primer postopne redukcije grafa, 1/2

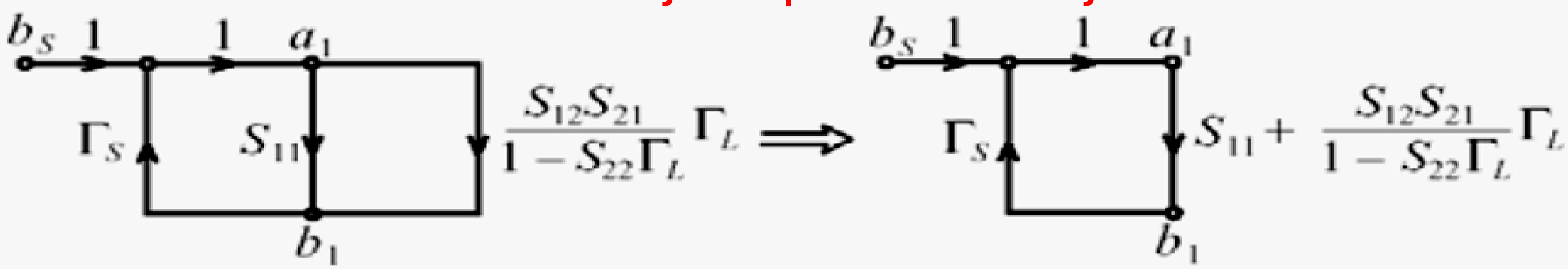
Korak 1: Podvojitev vozla a_2:



Korak 2: Odprava zanke in multiplikacija vej:

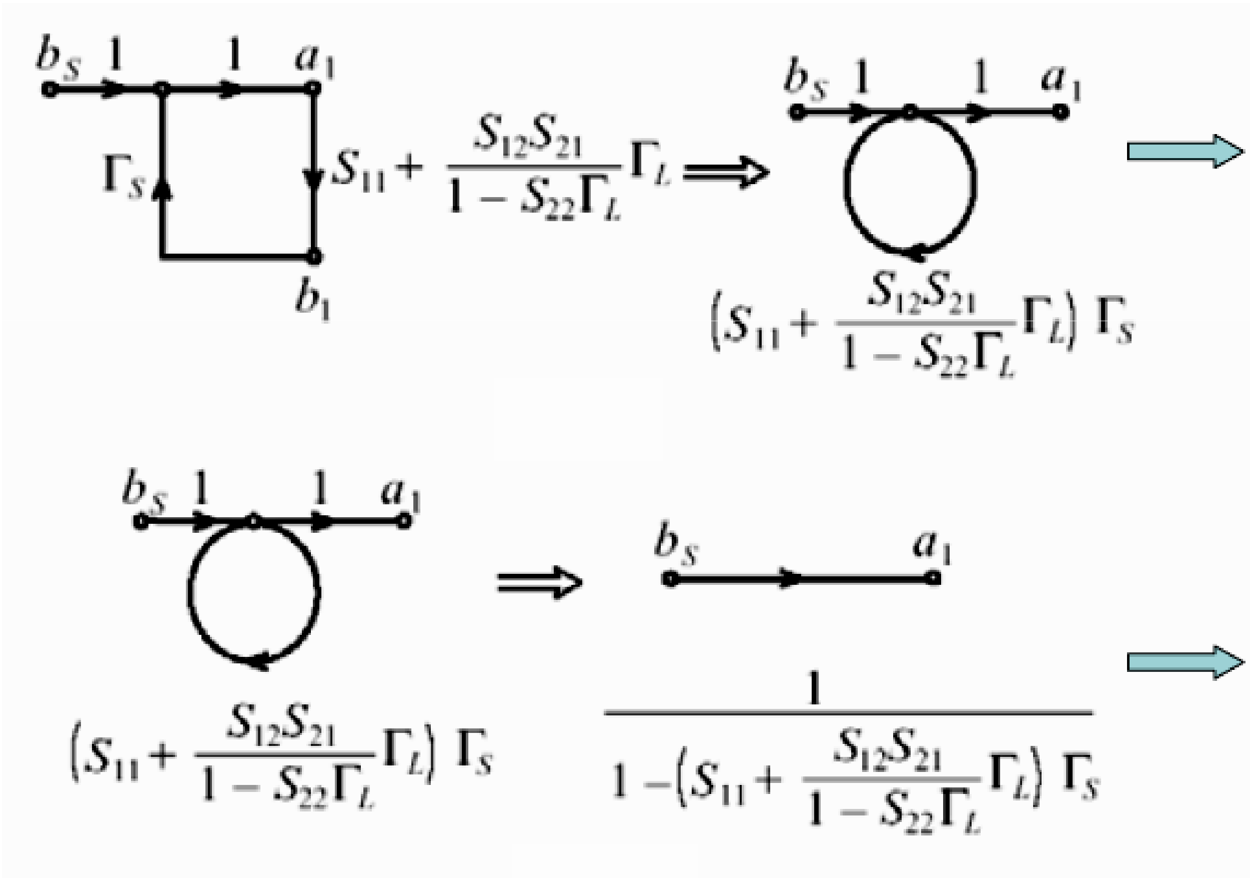


Korak 3: Adicija vzporednih vej:



Primer postopne redukcije grafa, 2/2

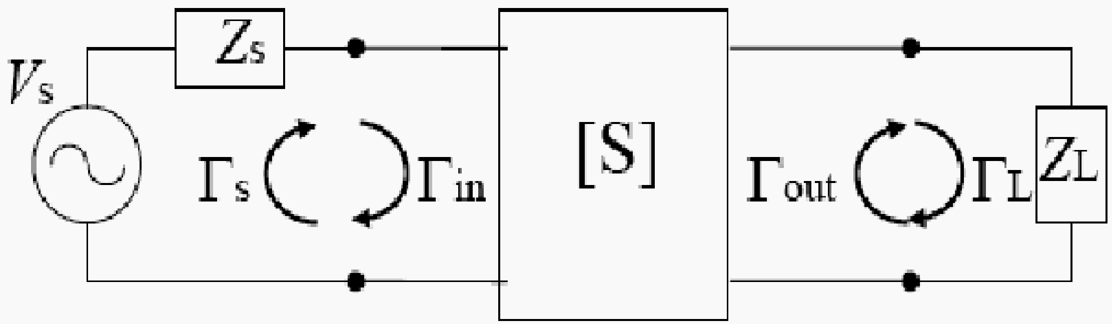
Korak 4: Podvojitev a_1 in določitev a_1 ter b_1 (vhodna odbojnost):

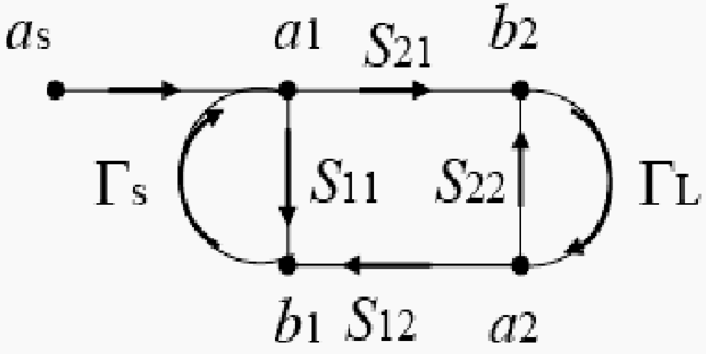


$$\Gamma_{in} = S_{11} + \frac{S_{21}S_{12}}{1 - S_{22}\Gamma_L}\Gamma_L$$

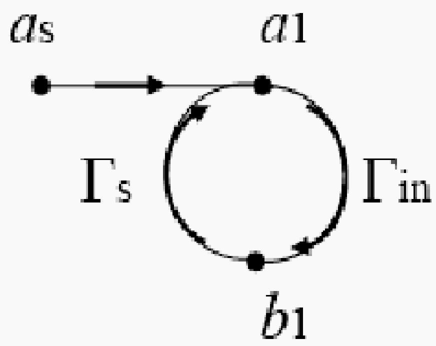
$$a_1 = \frac{b_s}{1 - \Gamma_{in}\Gamma_S}$$

Vhodna in izhodna odbojnost, metoda redukcije



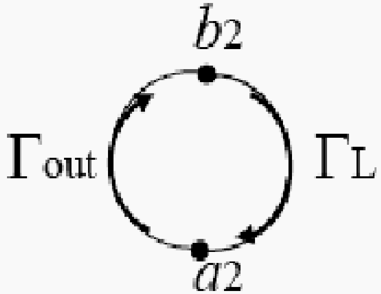


$$b_1 = a_1 S_{11} + a_1 S_{21} \Gamma_L S_{12} (1 + S_{22} \Gamma_L + \ldots) = a_1 S_{11} + a_1 \frac{S_{12} S_{21} \Gamma_L}{1 - S_{22} \Gamma_L}$$



$$\rightarrow \Gamma_{in} = \frac{b_1}{a_1} = S_{11} + \frac{S_{12} S_{21} \Gamma_L}{1 - S_{22} \Gamma_L}$$

$$b_2 = a_2 S_{22} + a_2 S_{12} \Gamma_S S_{21} (1 + S_{11} \Gamma_S + \ldots) = a_2 S_{22} + a_2 \frac{S_{12} S_{21} \Gamma_S}{1 - S_{11} \Gamma_S}$$



$$\Gamma_{out} = \frac{b_2}{a_2} = S_{22} + \frac{S_{12} S_{21} \Gamma_S}{1 - S_{11} \Gamma_S}$$

Masonovo pravilo nedotikajočih se zank

$$T = \frac{T_1[1 - \Sigma L(1)^{(1)} + \Sigma L(2)^{(1)} - .....] + T_2[1 - \Sigma L(1)^{(2)} + ...] + ...}{1 - \Sigma L(1) + \Sigma L(2) - \Sigma L(3) + ...}$$

kjer pomenijo:

T_1, T_2 ... koeficienti poti T_m, ki povezujejo vozle grafa

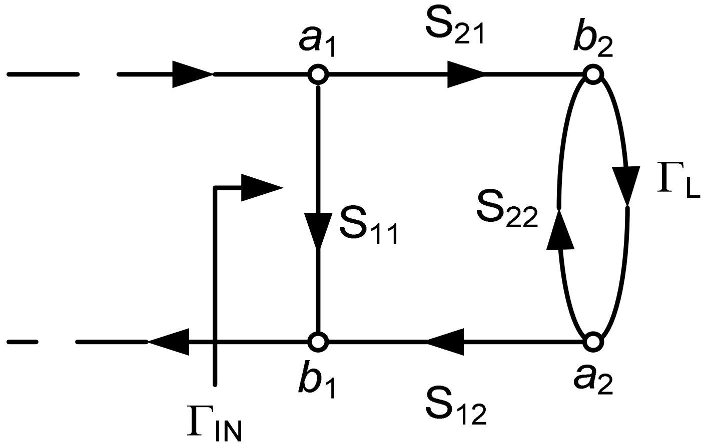
L(1) ... koeficient zanke prvega reda (produkt koeficientov vej, ki izhajajo iz vozla in se vanj vračajo)

L(2) ... koeficient zanke drugega reda (produkt koeficientov dveh nedotikajočih se zank prvega reda)

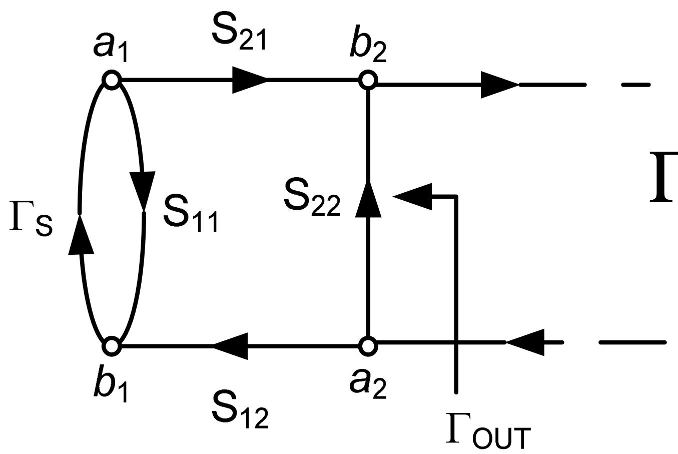
L(3) ... koeficient zanke tretjega reda (produkt koeficientov treh nedotikajočih se zank drugega reda)

$L(n)^{(T_m)}$ koeficient zanke n-tega reda, ki se ne dotika poti T_m

Vhodna in izhodna odbojnost 4-polnega vezja, Masonovo pravilo

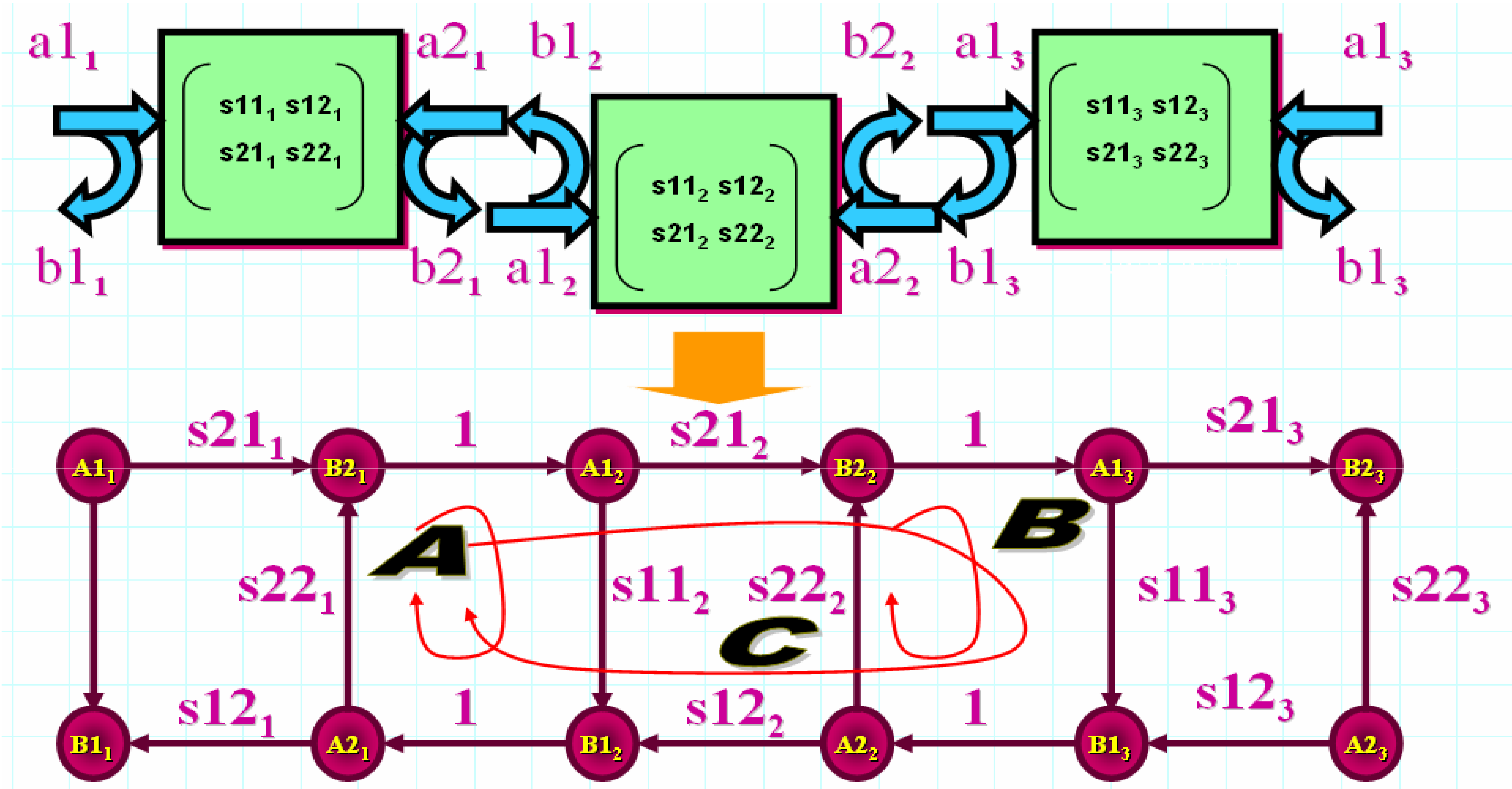


$$\Gamma_{IN} = \frac{b_1}{a_1} = \frac{S_{11}(1 - S_{22}\Gamma_L) + S_{21}\Gamma_L S_{12}}{1 - S_{22}\Gamma_L} = S_{11} + \frac{S_{12}S_{21}\Gamma_L}{1 - S_{22}\Gamma_L}.$$



$$\Gamma_{OUT} = \frac{b_2}{a_2} = \frac{S_{22}(1 - S_{11}\Gamma_S) + S_{21}\Gamma_S S_{12}}{1 - S_{11}\Gamma_S} = S_{22} + \frac{S_{12}S_{21}\Gamma_S}{1 - S_{11}\Gamma_S}.$$

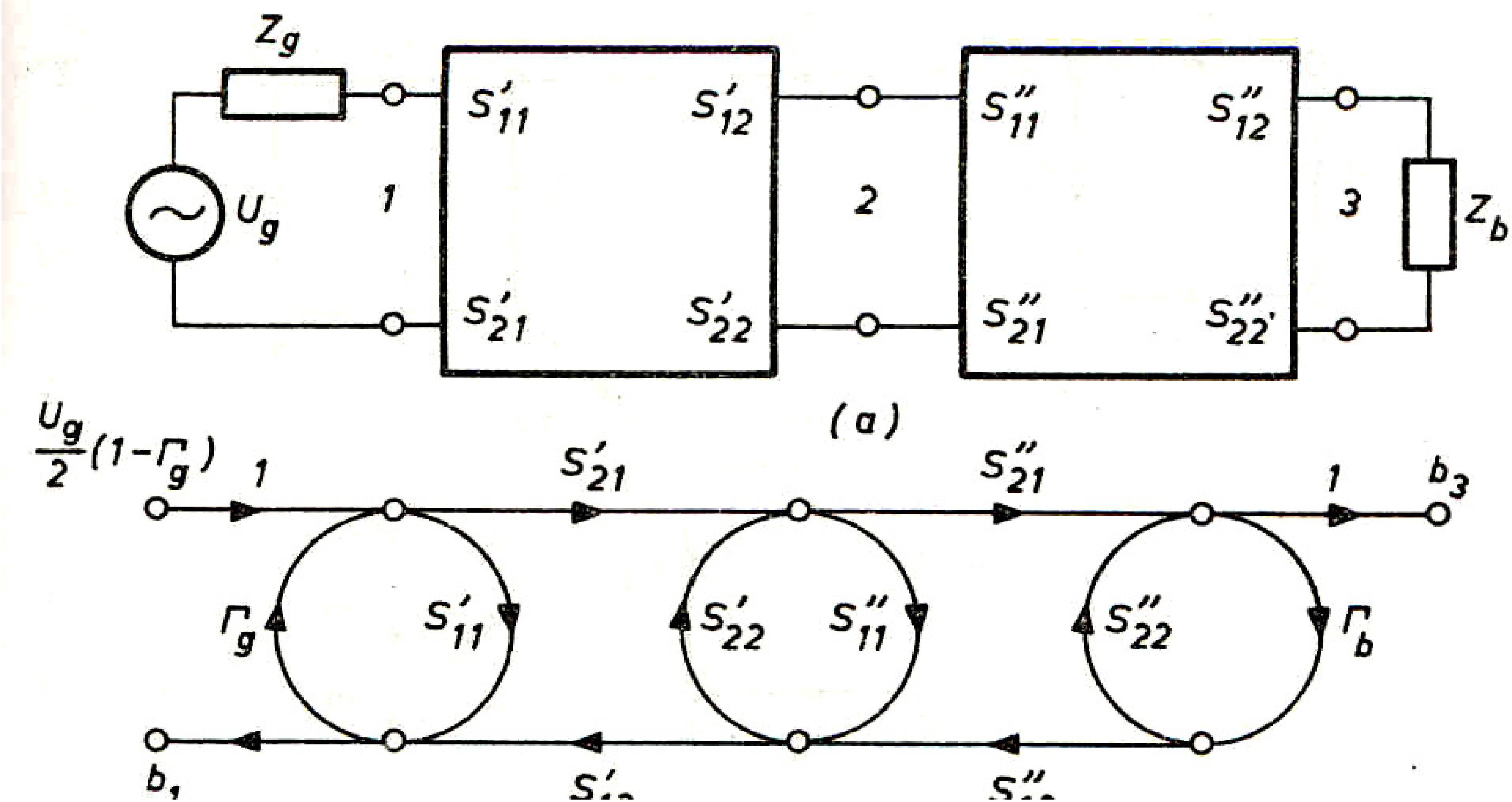
Kaskadna vezava po Masonovem pravilu



$$\frac{b6}{a1} = \frac{s21_1 \cdot s21_2 \cdot s21_3}{1 - \left(s22_2 \cdot s11_1 + s22_3 \cdot s11_2 + s11_3 \cdot s22_1 \cdot s12_2 \cdot s21_2\right) + s22_1 \cdot s11_2 \cdot s22_2 \cdot s11_3}$$

B C A B

Kaskada 4- polnih vezij 1/2



Kaskada 4- polnih vezij 2/2

Masonovo pravilo nedotikajočih se zank:

$$b_3 = \frac{U_g}{2}\,(1 - \Gamma_g)\,\frac{T_1}{1 - \Sigma L^{(1)} + \Sigma L^{(2)} - \Sigma L^{(3)}} \qquad T_1 = S'_{21}S''_{21}$$

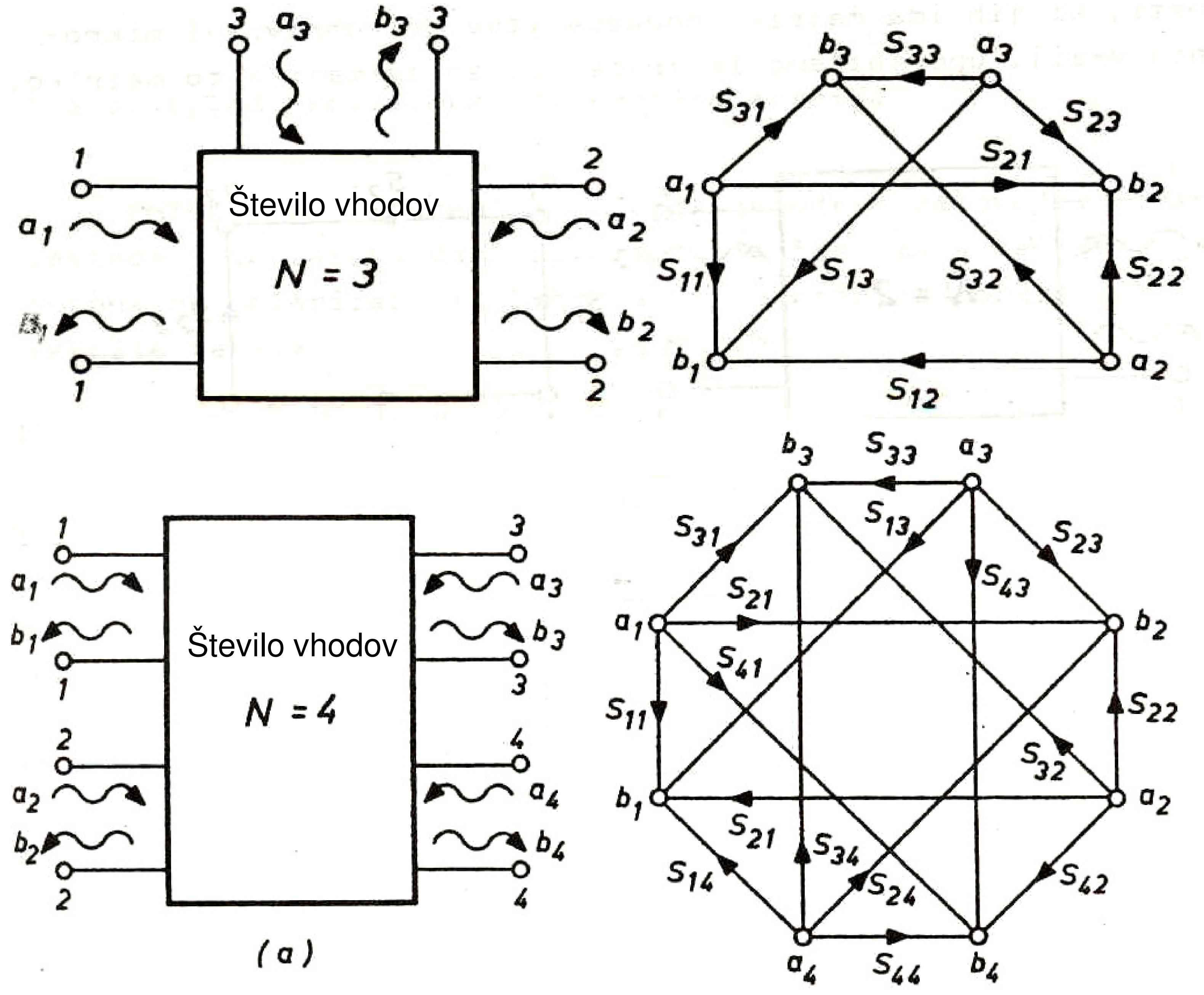
kjer so koeficienti zank:

$$\Sigma L^{(1)} = \Gamma_g S'_{11} + S'_{22}S''_{11} + S''_{22}\Gamma_b + \Gamma_g S'_{21}S''_{11}S'_{12} + S'_{22}S''_{21}\Gamma_b S''_{12}$$
$$+ \Gamma_g S'_{21}S''_{21}\Gamma_b S''_{12}S'_{12},$$

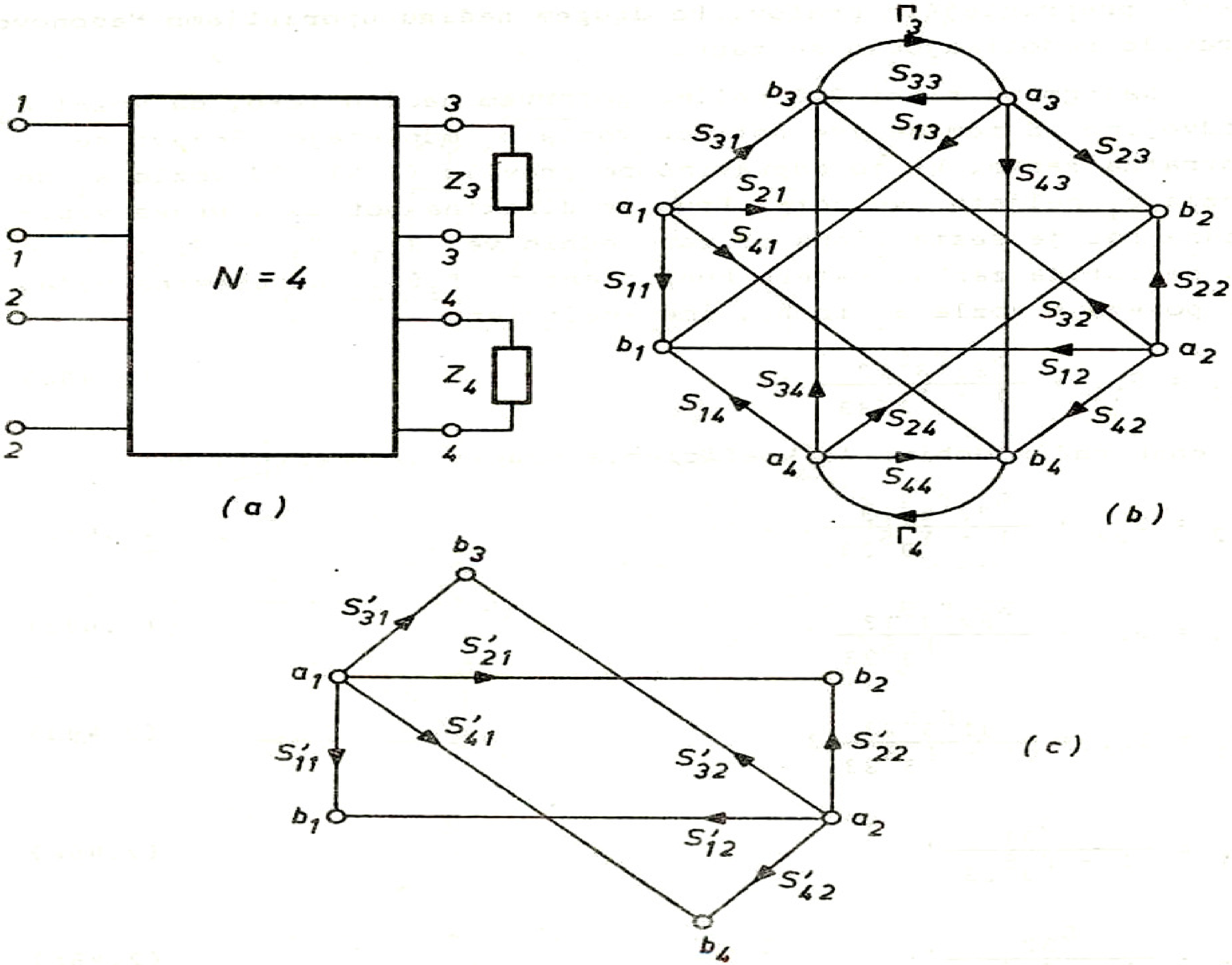
$$\Sigma L^{(2)} = \Gamma_g S'_{11}S'_{22}S''_{11} + S'_{22}S''_{11}S''_{22}\Gamma_b + \Gamma_g S'_{11}S''_{22}\Gamma_b +$$
$$+ \Gamma_g S'_{21}S''_{11}S'_{12}S''_{22}\Gamma_b + \Gamma_g S'_{11}S'_{22}S''_{21}\Gamma_b S''_{12},$$

$$\Sigma L^{(3)} = \Gamma_g S'_{11}S'_{22}S''_{11}S''_{22}\Gamma_b .$$

Smerni graf 6- in 8-polnega vezja



Redukcija smernega grafa 8- polnega vezja



Koeficient S'$_{11}$ reduciranega grafa 8-polnega vezja

Koeficienti direktnih poti T_1 ($a_1 - b_1$) :

$$T_1 = S_{11},$$
$$T_2 = S_{31}\Gamma_3 S_{13},$$
$$T_3 = S_{41}\Gamma_4 S_{14},$$
$$T_4 = S_{31}\Gamma_3 S_{43}\Gamma_4 S_{14},$$
$$T_5 = S_{41}\Gamma_4 S_{34}\Gamma_3 S_{13}.$$

Koeficienti zank direktnih poti T_2 in T_3 :

$$L_2^{(1)} = \Gamma_4 S_{44},$$
$$L_3^{(1)} = \Gamma_3 S_{33}.$$

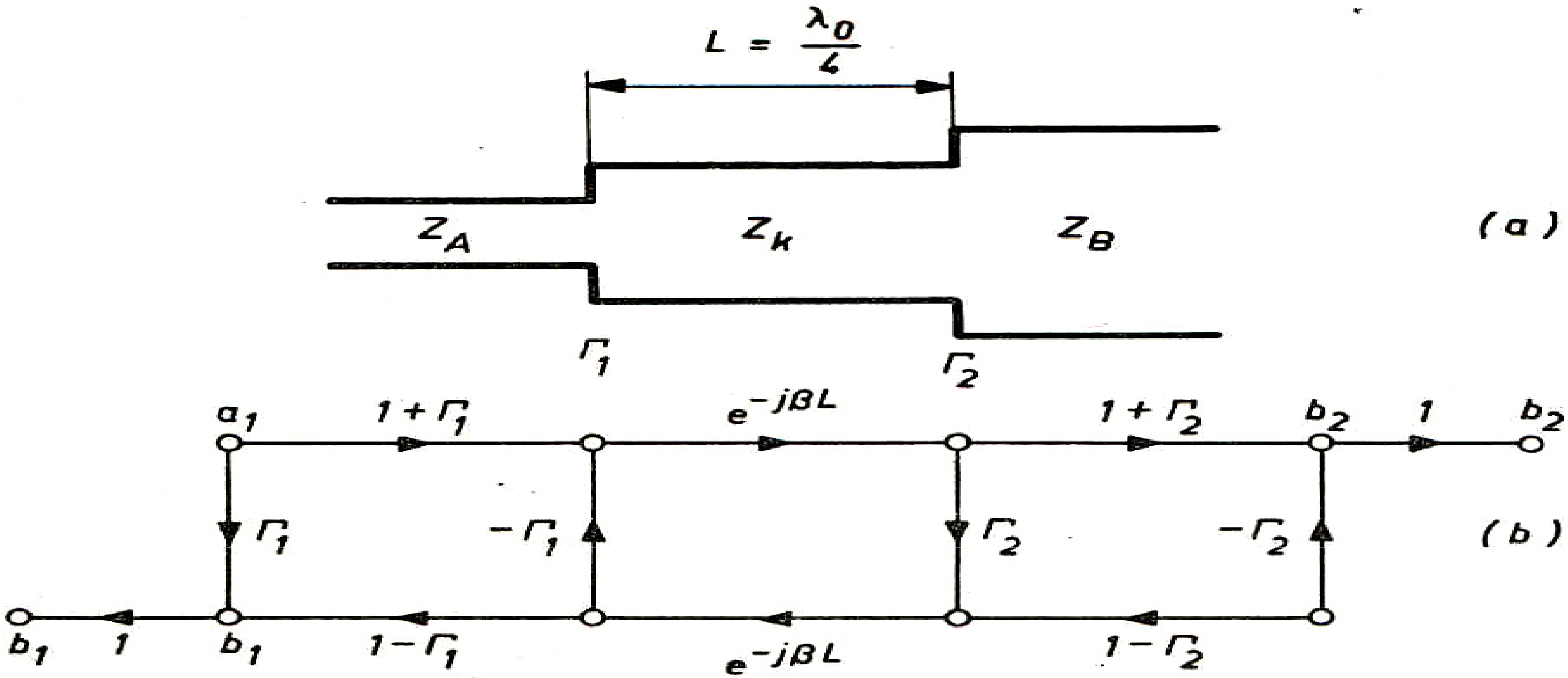
Koeficienti zank poti T_2 in T_3:

$$L_1^{(1)} = \Gamma_3 S_{33} + \Gamma_4 S_{44} + \Gamma_3 S_{43}\Gamma_4 S_{34},$$
$$L_1^{(2)} = \Gamma_3 S_{33}\Gamma_4 S_{44}.$$

Koeficient S'$_{11}$:

$$S'_{11} = S_{11} + \frac{S_{31}\Gamma_3 S_{13}(1-\Gamma_4 S_{44}) + S_{41}\Gamma_4 S_{14}(1-\Gamma_3 S_{33}) + \Gamma_3\Gamma_4(S_{31}S_{43}S_{14} + S_{41}S_{34}S_{13})}{1-\Gamma_3 S_{33} - \Gamma_4 S_{44} - \Gamma_3 S_{43}\Gamma_4 S_{34} + \Gamma_3 S_{33}\Gamma_4 S_{44}}.$$

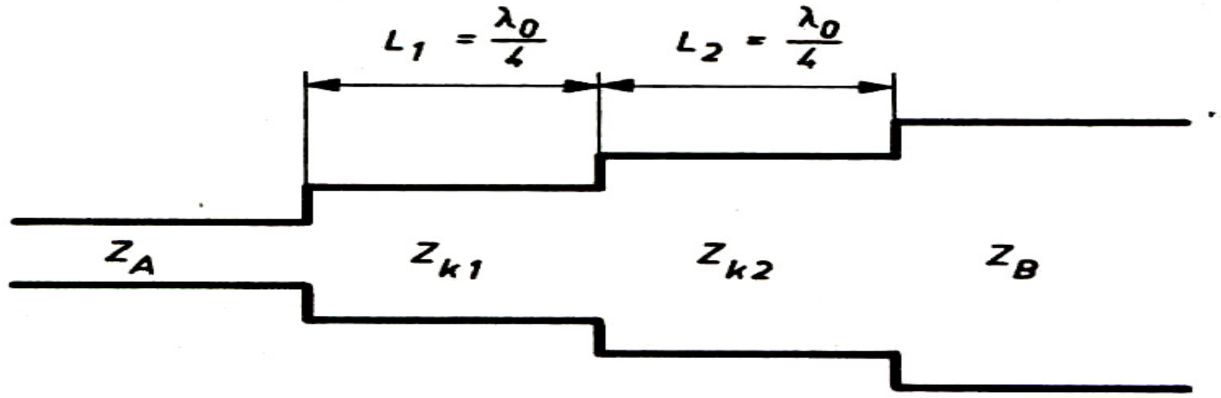
Enostopenjski impedančni λ/4 transformator

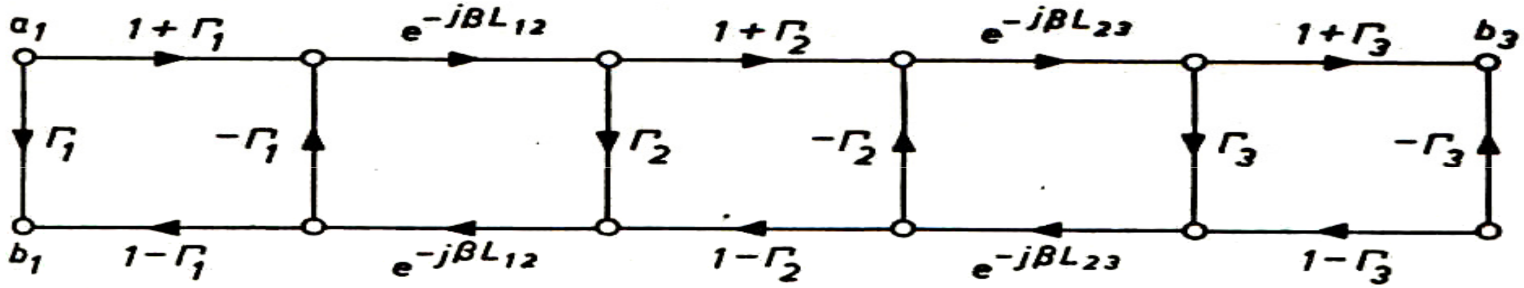


$$\Gamma_{vh} = \frac{b_1}{a_1} = \Gamma_1 + \frac{(1-\Gamma_1^2)\Gamma_2 e^{-j\beta 2L}}{1+\Gamma_1\Gamma_2 e^{-j\beta 2L}} = \frac{\Gamma_1+\Gamma_2 e^{-j\beta 2L}}{1+\Gamma_1\Gamma_2 e^{-j\beta 2L}}$$

$\Gamma_1 = \Gamma_2$ ali $\frac{Z_k/Z_A - 1}{Z_k/Z_A + 1} = \frac{Z_B/Z_k - 1}{Z_B/Z_k + 1}$ ali $Z_k^2 = Z_A Z_B$

Dvostopenjski impedančni λ/4 transformator





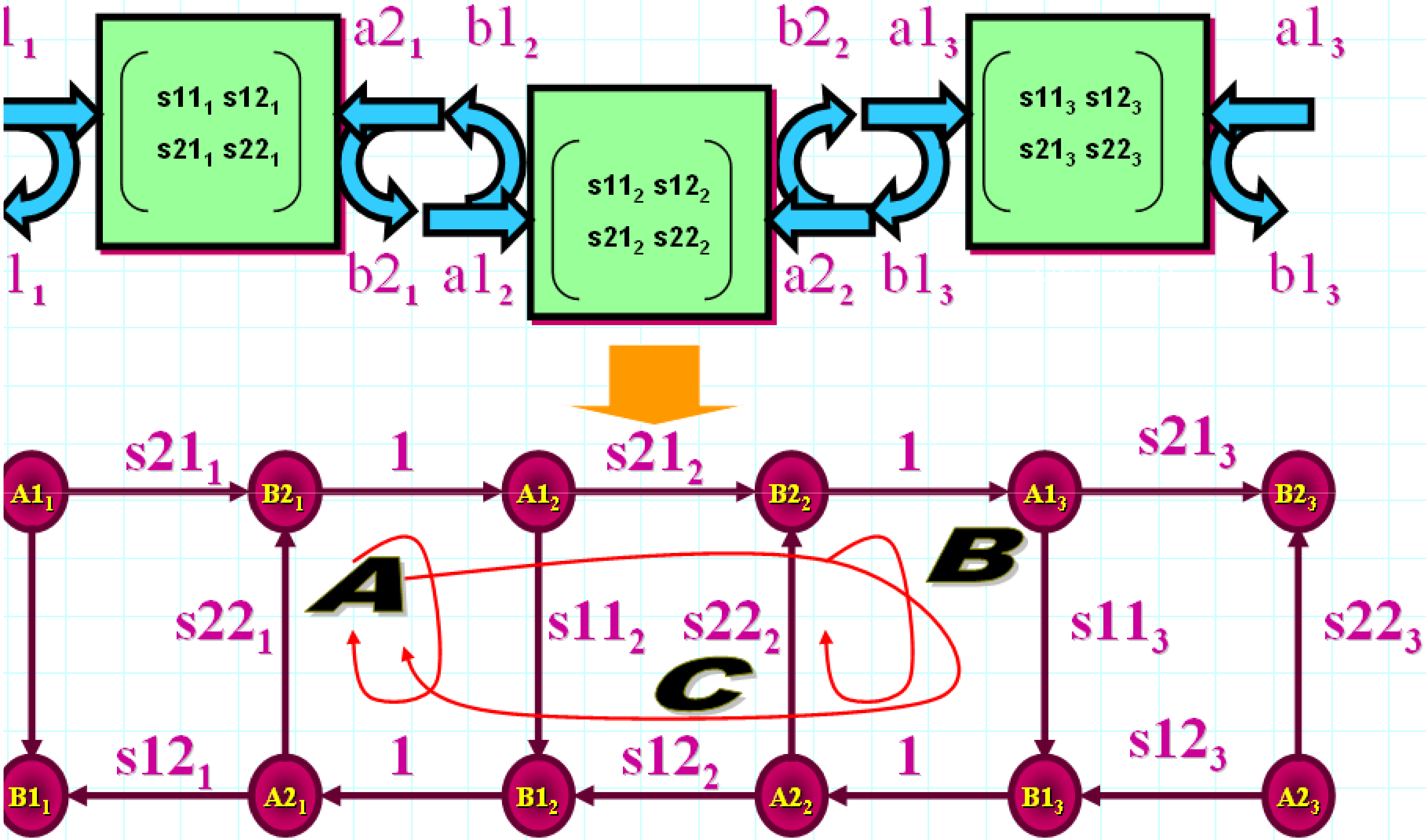
$$\Gamma_{vh} \doteq \Gamma_1 + \frac{(1-\Gamma_1^2)\Gamma_2 e^{-j\beta 2L_{12}}(1+\Gamma_2\Gamma_3 e^{-j\beta 2L_{23}}) + (1-\Gamma_1^2)(1-\Gamma_2^2)\Gamma_3 e^{-j\beta 2(L_{12}+L_{23})}}{1+\Gamma_1\Gamma_2 e^{-j\beta 2L_{12}} + \Gamma_2\Gamma_3 e^{-j\beta 2L_{23}} + \Gamma_1\Gamma_3(1-\Gamma_2^2) e^{-j\beta 2(L_{12}+L_{23})}};$$

$$\Gamma_{vh} \doteq \Gamma_1 + \frac{\Gamma_2 e^{-j\beta 2L_{12}} + \Gamma_3 e^{-j\beta 2(L_{12}+L_{23})}}{1+\Gamma_1\Gamma_2 e^{-j\beta 2L_{12}} + \Gamma_2\Gamma_3 e^{-j\beta 2L_{23}} + \Gamma_1\Gamma_3 e^{-j\beta 2(L_{12}+L_{23})}}$$

Sklep

- Grafi signalnega toka so praktična metoda za ocenjevanje valovnih pojavov v mikrovalovni praksi.
- Metodo redukcije grafov uporabljamo pri reševanju preprostejših vezij. Masonovo metodo uporabljamo pri reševanju kompleksnih vezij, grafi katerih imajo zanke višjega reda.
- Smerni grafi dajejo jasnejšo predstavo valovnih pojavov in omogočajo upoštevanje in vrednotenje zanemaritev.
- Alternativa obravnave mikrovalovnih vezij s smernimi grafi je računalniška analiza, ki temelji na S-parametrih.
- Smerni grafi so idealen pripomoček za analizo merilnih napak.

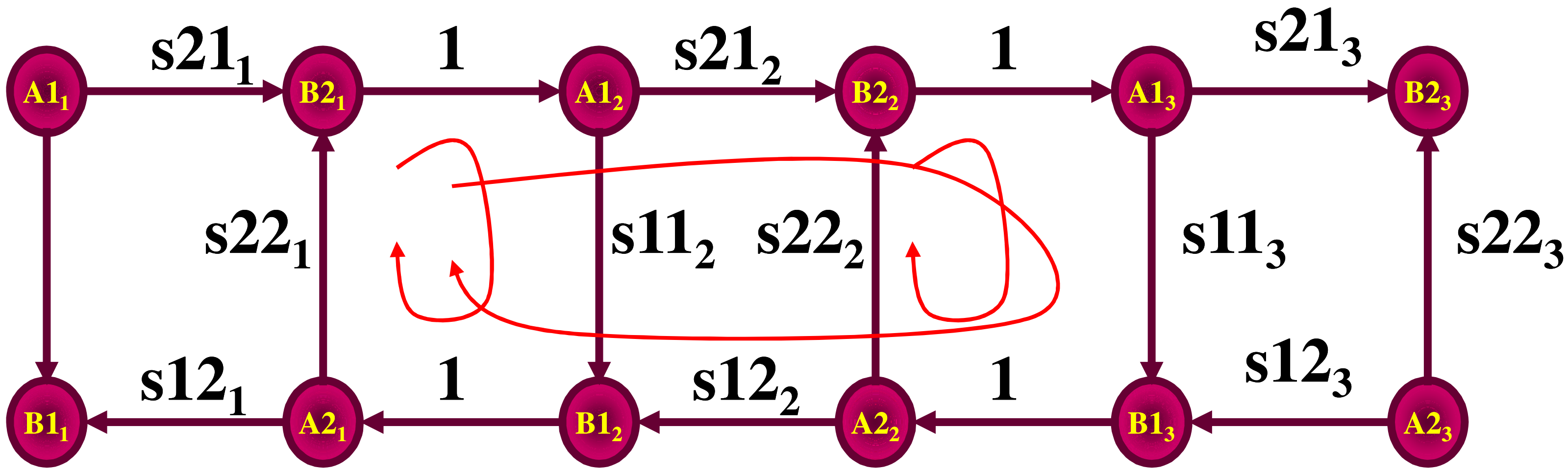
eating The signal flow graph



We map output a to input b and visa versa.

Next we define all the loops

Loop "A" and "B" do not touch each other



$$\frac{b6}{a1} = \frac{s21_1 \cdot s21_2 \cdot s21_3}{1 - \left(s22_2 \cdot s11_1 + s22_3 \cdot s11_2 + s11_3 \cdot s22_1 \cdot s12_2 \cdot s21_2\right) + s22_1 \cdot s11_2 \cdot s22_2 \cdot s11_3}$$

Variables'descriptions (1)

P_1, P_2, (and so on)

= paths connecting the dependent and independent variables whose transfer function *T* is to be determined.

A path is defined as a set of consecutive, codirectional branches along which no node is encountered more than once as we move in the graph from the independent to the dependent node.

Σ ***L*(1)**

= the sum of all first-order loops. A first-order loop is defined as the product of the branches encountered in a round trip as we move from a node in the direction of the arrows back to that original node.

Variables'descriptions (2)

Σ *L*(2)

= the sum of all second-order loops. A second-order loop is defined as the product of any two nontouching first-order loops.

Σ *L*(3)

= the sum of all third-order loops. A third-order loop is defined as the product of any three nontouching first-order loops.

Σ *L*(4), Σ *L*(5), and so on represent fourth-, fifth-, and higher order loops.

Variables'descriptions (3)

Σ $\boldsymbol{L(1)^{(P)}}$

= the sum of all first-order loops that do not touch the path *P* between the independent and dependent variables.

Σ $\boldsymbol{L(2)^{(P)}}$

= the sum of all second-order loops that do not touch the path *P* between the independent and dependent variables.

Σ $\boldsymbol{L(3)^{(P)}}$, Σ $\boldsymbol{L(4)^{(P)}}$ and so on represent third-, fourth-, and higher order loops that do not touch the path *P*.

ason's Rule ~ Non-Touching Loop Rule

$$T = \frac{\sum_{k} T_k \left(1 + \sum_{mk} (-1)^{mk} L(mk)\Big|^{(k)}\right)}{\left(1 + \sum_{mk} (-1)^{mk} L(mk)\right)}$$

is the transfer function (often called gain)

. is the transfer function of the k^{th} forward path

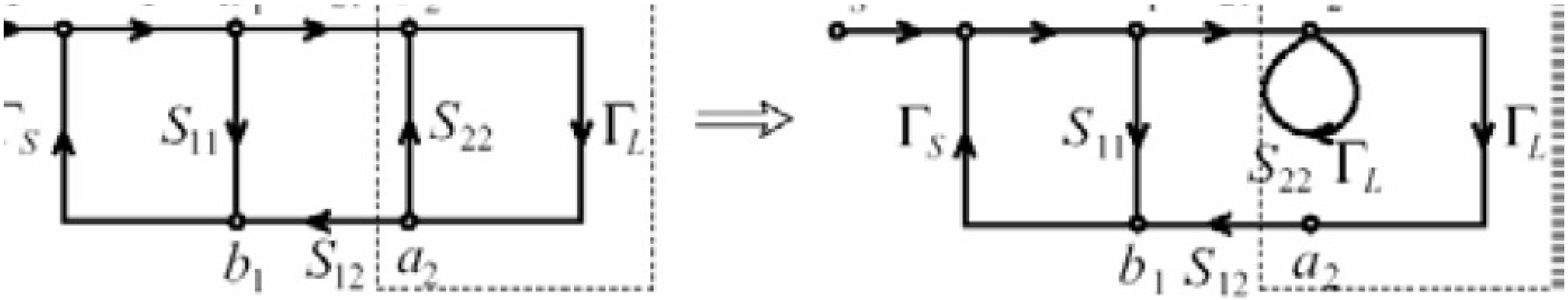
$mk)$ is the product of non touching loop gains on path k

ken mk at time.

$mk)\big|^{(k)}$ is the product of non touching loop gains on path k

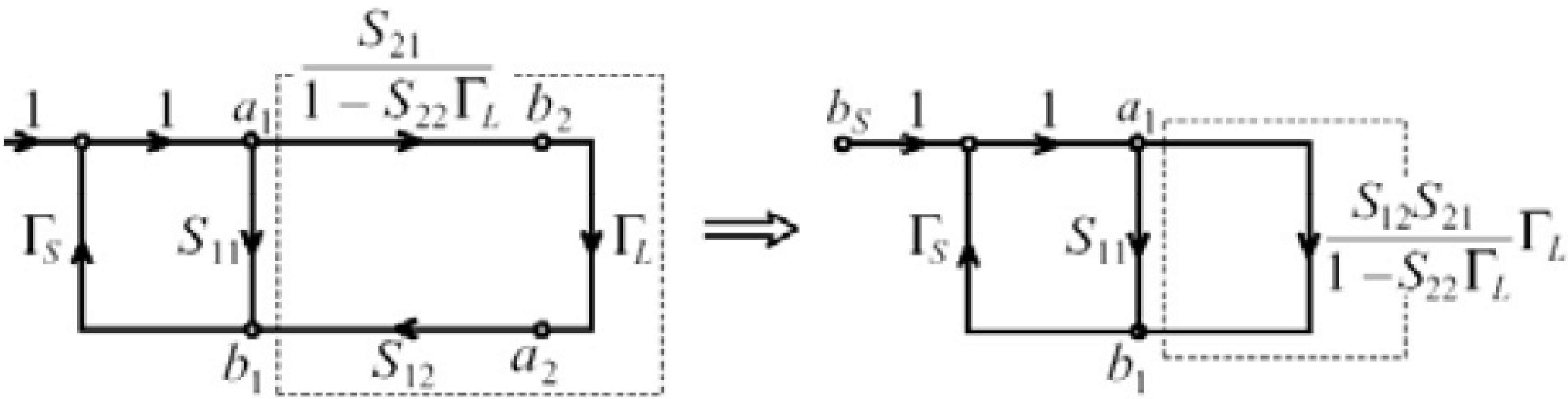
ken mk at a time but not touching path k.

$k=1$ means all individual loops



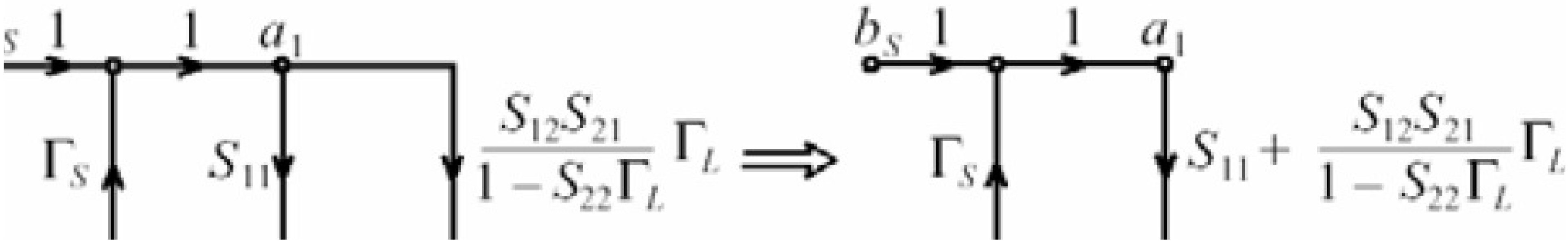
S_{11}
S_{22}
Γ_L
b_1
S_{12}
a_2
Γ_S
$S_{22}\Gamma_L$

Step 1



$\frac{S_{21}}{1-S_{22}\Gamma_L}$
1
1
a_1
b_2
Γ_S
S_{11}
Γ_L
b_1
S_{12}
a_2
b_S
$\frac{S_{12}S_{21}}{1-S_{22}\Gamma_L}\Gamma_L$

Step 2



1
1
a_1
Γ_S
S_{11}
$\frac{S_{12}S_{21}}{1-S_{22}\Gamma_L}\Gamma_L$
b_S
$S_{11}+\frac{S_{12}S_{21}}{1-S_{22}\Gamma_L}\Gamma_L$