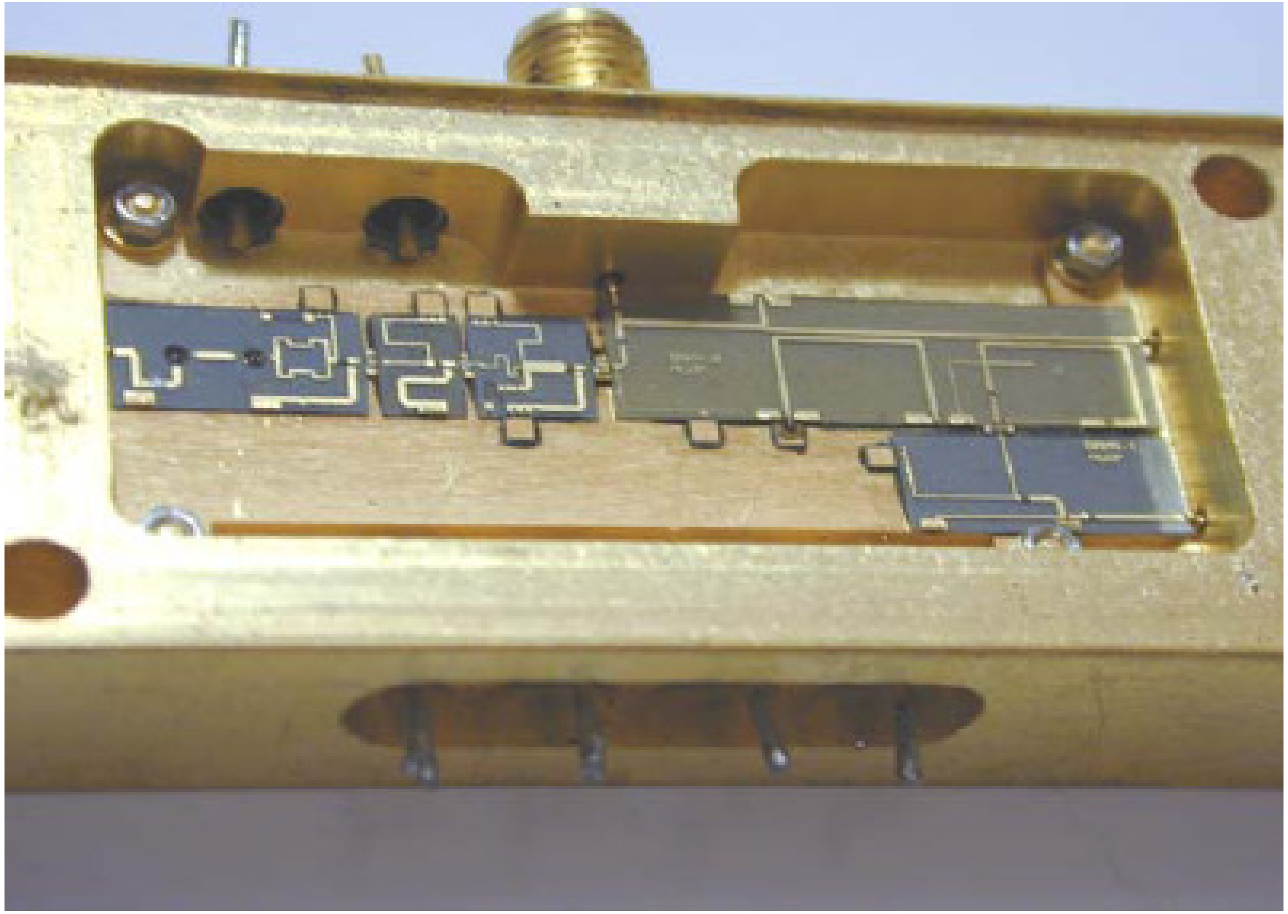
Mikrovalovna vezja in naprave



Mobitel d.d., izobraževanje

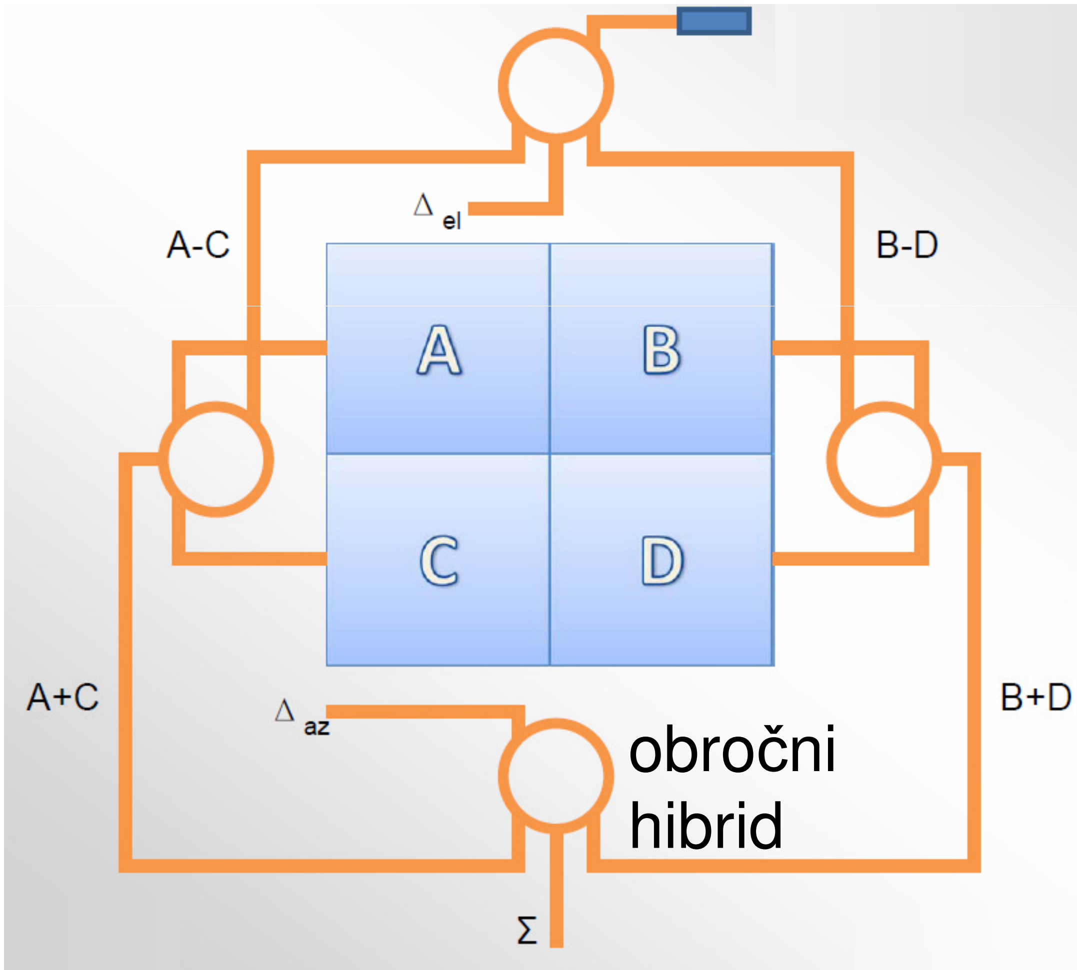
6. 11. 2009, predavanje 27

Prof. dr. Jožko Budin

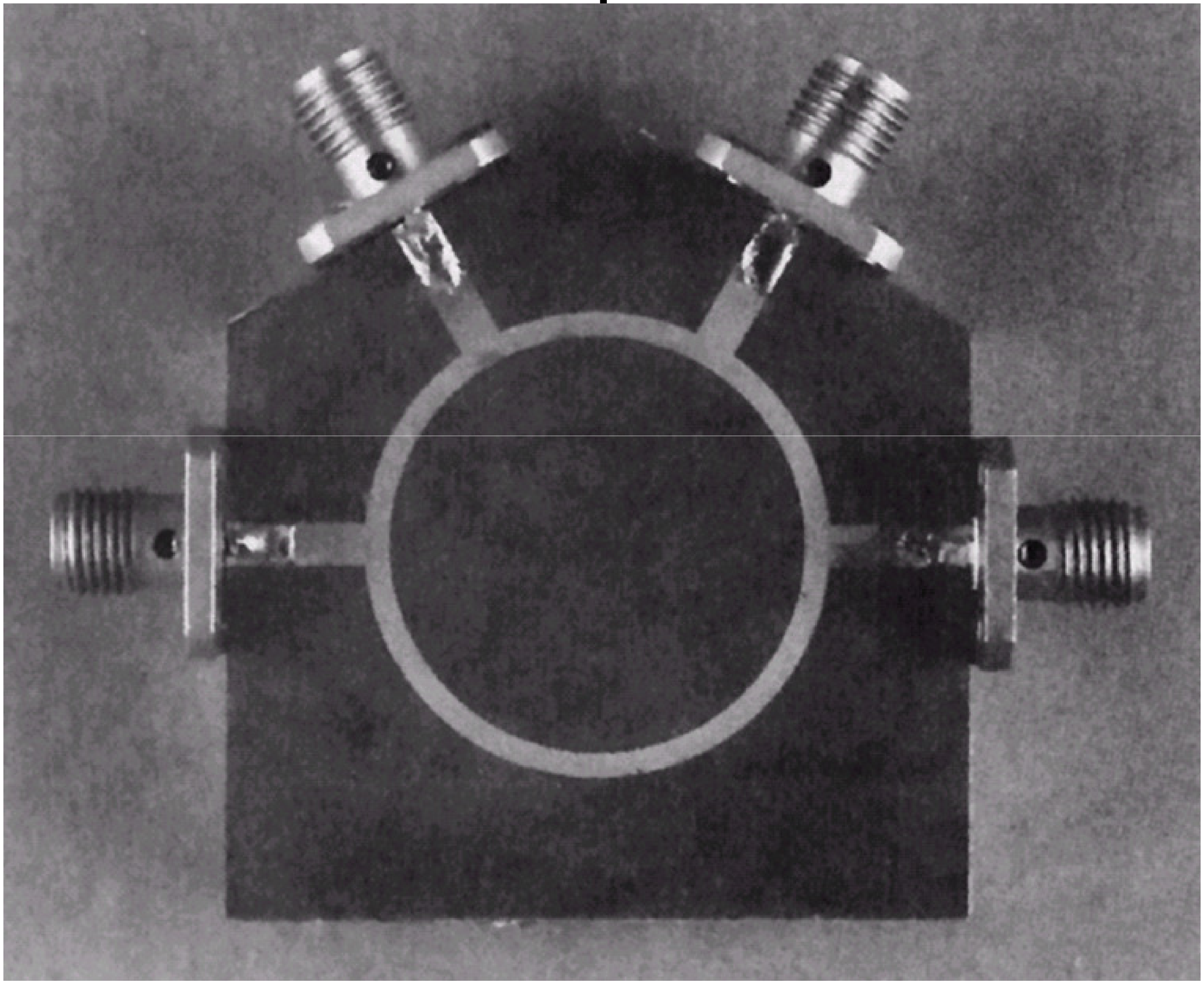
Vsebina

1. 4- polna vezja
- Splošne lastnosti
- Atenuator
- Izolator
2. 6- polna vezja
- Splošne lastnosti
- Delilnik
- Cirkulator
3. 8- polna vezja
- Splošne lastnosti
- Hibrid
- Smerni sklopnik
4. 2N- polna vezja

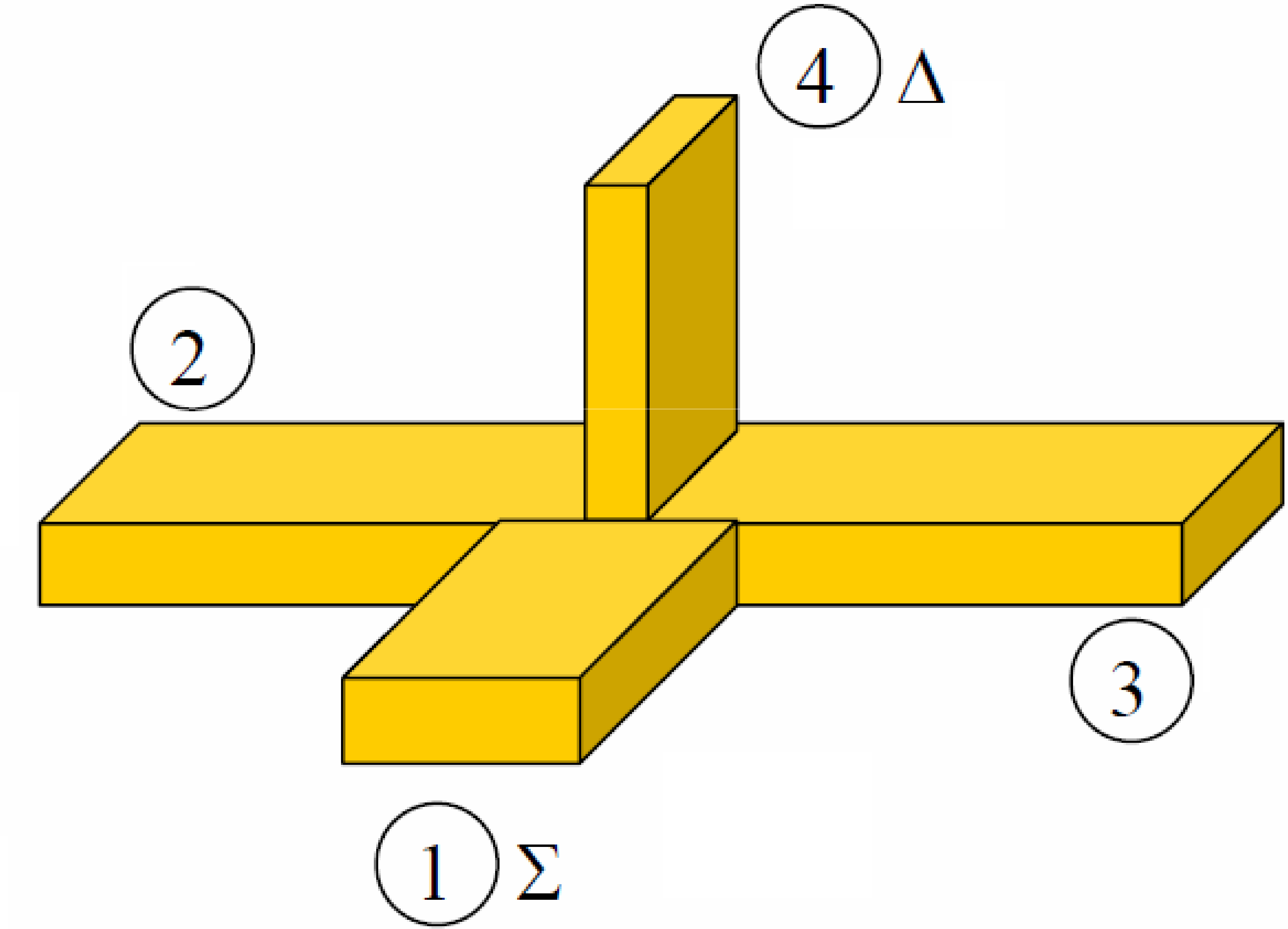
Vzbujanje sumarnega in diferenčnega diagrama 4-segmentne antene po azimutu in elevaciji



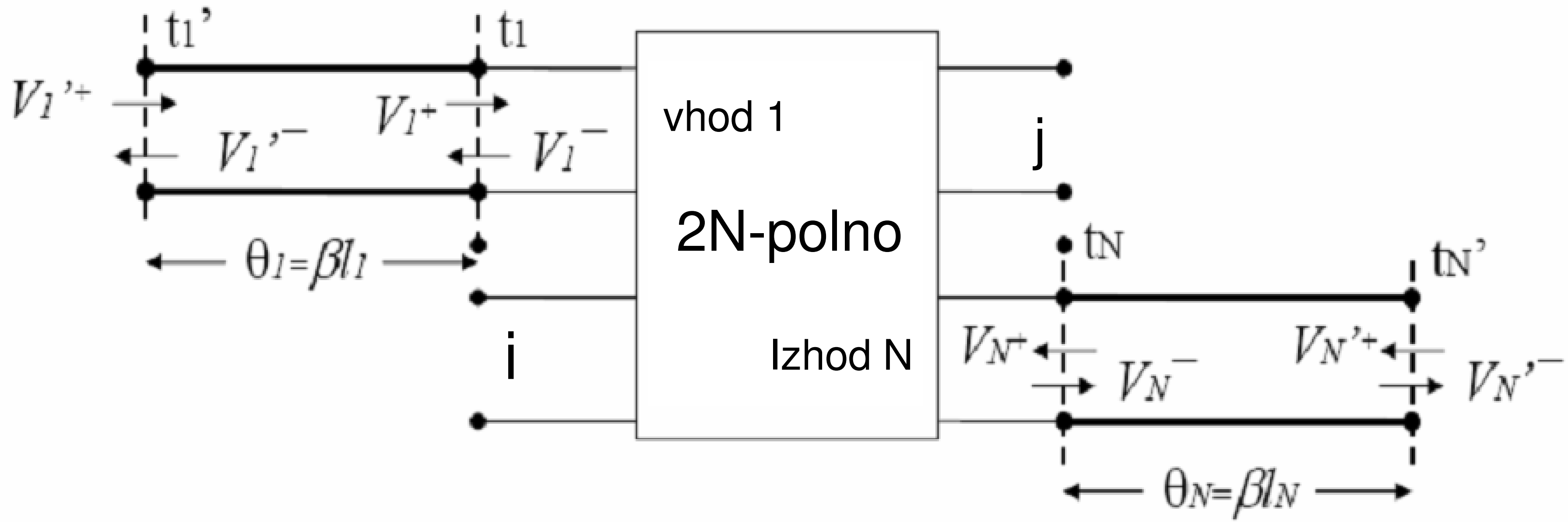
Obročni hibrid – planarna tehnika



Magični T – valovodna tehnika



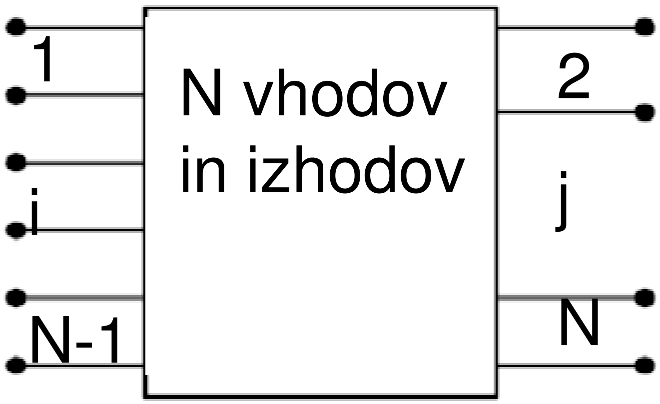
2N – polno (N – vhodno) vezje



$$[V^-]=[S]\,[V^+],\quad \begin{bmatrix} V_1^- \\ V_2^- \\ \bullet \\ \bullet \\ V_N^- \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & \bullet & \bullet & S_{1N} \\ S_{21} & \bullet & \bullet & \bullet & S_{2N} \\ \bullet & \bullet & \bullet & \bullet & \bullet \\ \bullet & \bullet & \bullet & \bullet & \bullet \\ S_{N1} & S_{N2} & \bullet & \bullet & S_{NN} \end{bmatrix} \begin{bmatrix} V_1^+ \\ V_2^+ \\ \bullet \\ \bullet \\ V_N^+ \end{bmatrix},\quad S_{ij} = \left.\frac{V_i^-}{V_j^+}\right|_{V_k^+=0,k\neq j} = \left.\frac{\text{odziv}_i}{\text{vir}_j}\right|_{V_k^+=0,k\neq j}$$

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:

$$S_{ji}=b_j/a_i$$

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: $[S]^* = [S]^{-1}$

Unitarnost matrike [S]

1. Matrična izražava: $([S]^*)^T [S] = [1]$

$([S]^*)^T = [S]^H$ *Hermitska matrika*

2. Algebraična izražava:

$$\sum_{k=1}^{N} S_{ki} S_{kj}^* = 1 \qquad i = j$$

$$\sum_{k=1}^{N} S_{ki} S_{kj}^* = 0 \qquad i \neq j$$

ali:

$$\sum_{k=1}^{N} S_{ki} S_{kj}^* = \delta_{ij}$$

Unitarne enačbe 4- polnega vezja

$$\left(S^*\right)^T S = \begin{pmatrix} S_{11}^* & S_{21}^* \\ S_{12}^* & S_{22}^* \end{pmatrix} \begin{pmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$$

$$|S_{11}|^2 + |S_{21}|^2 = 1$$

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

$$S_{11}^* S_{12} + S_{21}^* S_{22} = 0$$

$$|S_{11}||S_{12}| = |S_{21}||S_{22}| \quad \text{and}$$

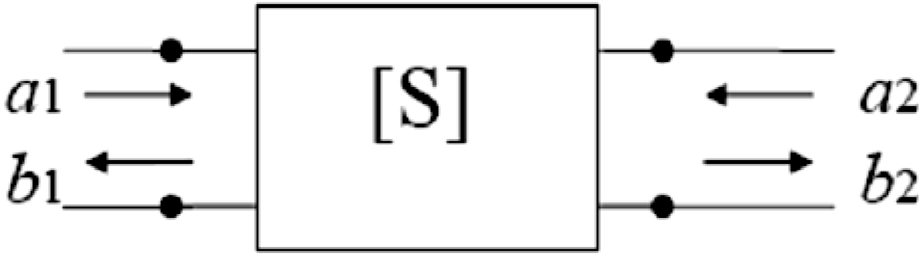
$$-\arg S_{11} + \arg S_{12} = -\arg S_{21} + \arg S_{22} + \pi$$

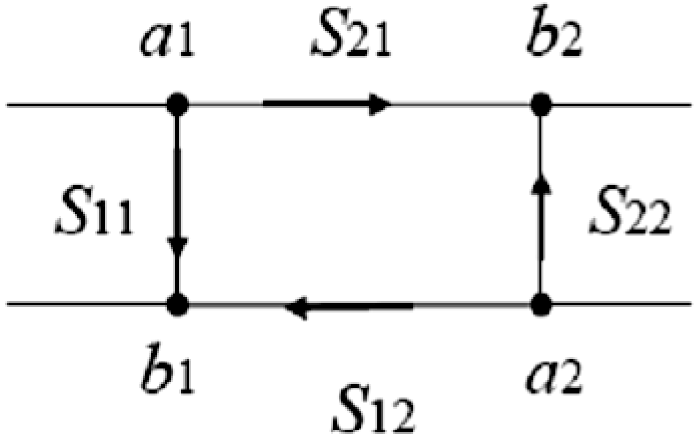
$$|S_{11}| = |S_{22}|, \quad |S_{12}| = |S_{21}|$$

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

- Splošno 4- polno vezje je določeno z osmimi podatki: štirimi absolutnimi vrednostmi in štirimi faznimi koti
- 4- polno vezje brez izgub je popolnoma določeno z eno absolutno vrednostjo in tremi faznimi koti.

Slabljenje 4- polnega vezja





- Matrične enačbe:

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

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

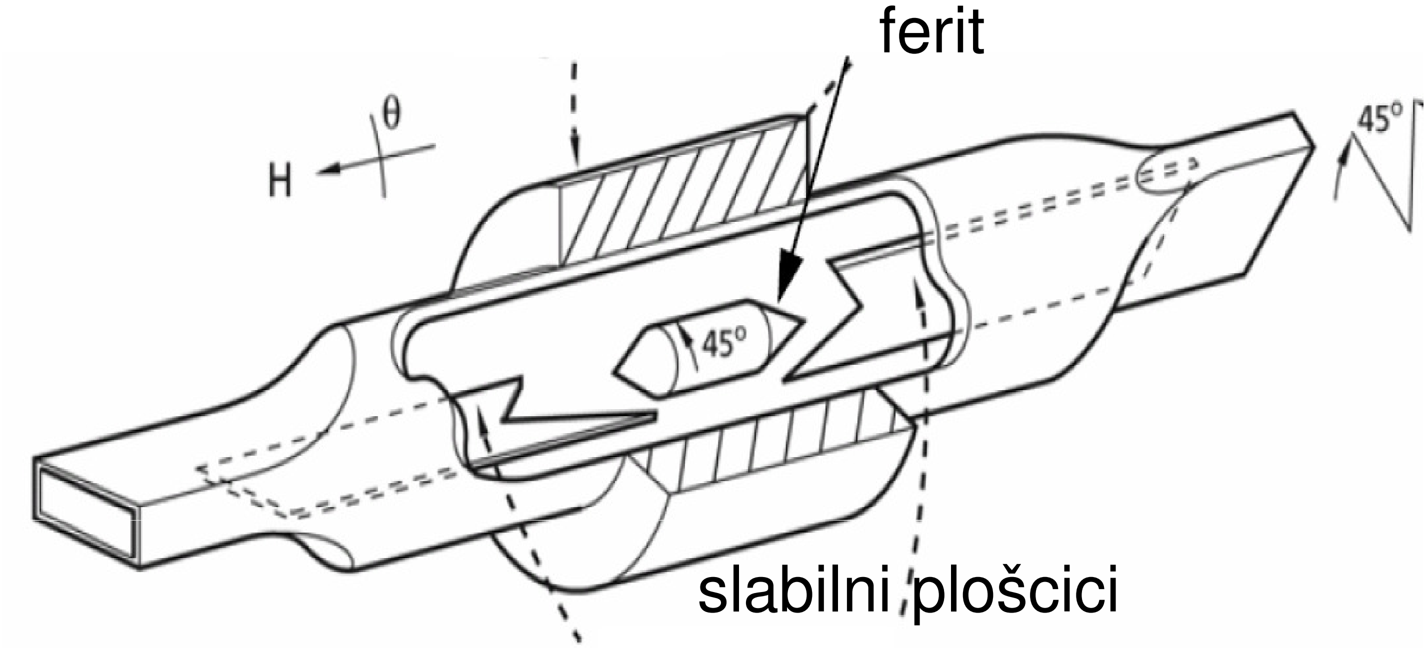
Odbojno slabljenje na vhodu 1 (izhod prilagojen)

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

Prenosno slabljenje z vhoda 1 na prilagojen izhod 2

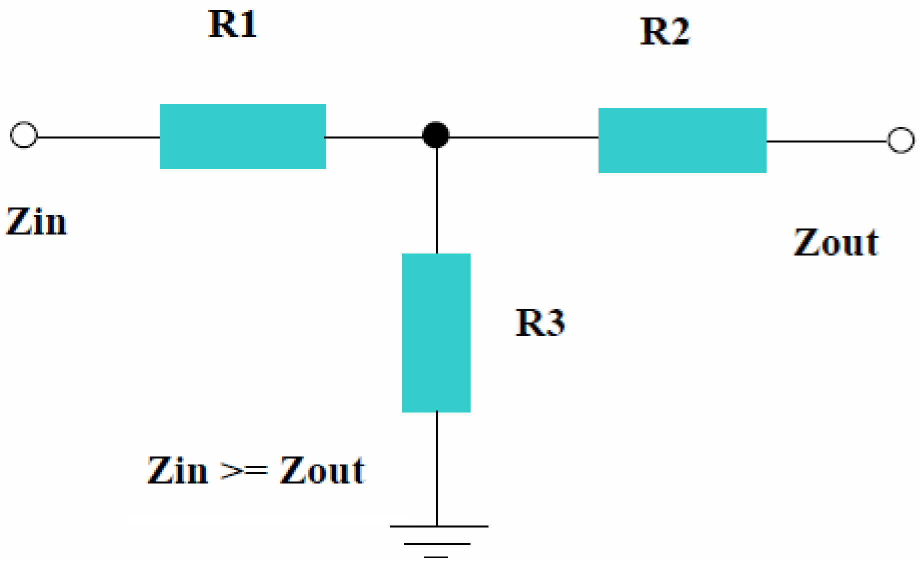
$$-20\log\left|\frac{b_2}{a_1}\right| = -20\log\left|S_{21}\right|$$

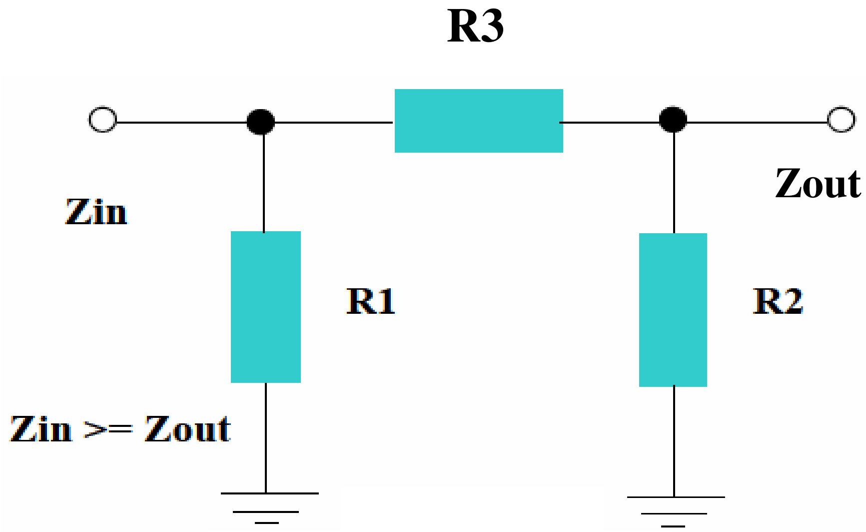
Izolator



- Izolator je sestavljen iz (vhodnega in zasukanega izhodnega) pravokotnega valovoda, srednjega krožnega valovoda s feritom in dveh slabilnih ploščic.
- Električno polje (rod TE10) iz levega valovoda se zaradi delovanja ferita zasuka za kot 45^0 v nasprotni smeri urnega kazalca in stoji pravokotno na slabilni ploščici izhodnega valovoda. Slabljenja ni.
- Električno polje iz desnega izhodnega valovoda se zasuka za 45^0 v smeri urnega kazalca in leži vzporedno na slabilni ploščici vhodnega valovoda. Slabljenje je.
- Izolator je nerecipročna naprava, ki v eno smer prepušča in v drugo smer slabi.

Atenuator vezave T in Π





$$R3 = \frac{2\sqrt{Zin * Zout * 10^{\frac{L}{10}}}}{10^{\frac{L}{10}} - 1}$$

$$R2 = \frac{10^{\frac{L}{10}} + 1}{10^{\frac{L}{10}} - 1} Zout - R3$$

$$R2 = \frac{10^{\frac{L}{10}} + 1}{10^{\frac{L}{10}} - 1} Zin - R3$$

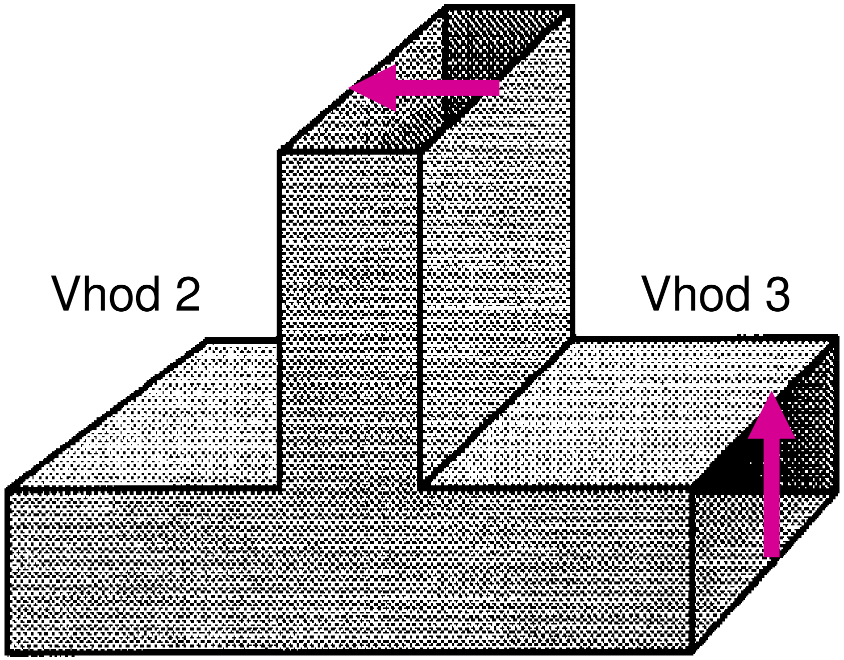
L slabljenje
v dB

$$R3 = \frac{1}{2}\left(10^{\frac{L}{10}} - 1\right)\sqrt{\frac{Zin * Zout}{10^{\frac{L}{10}}}}$$

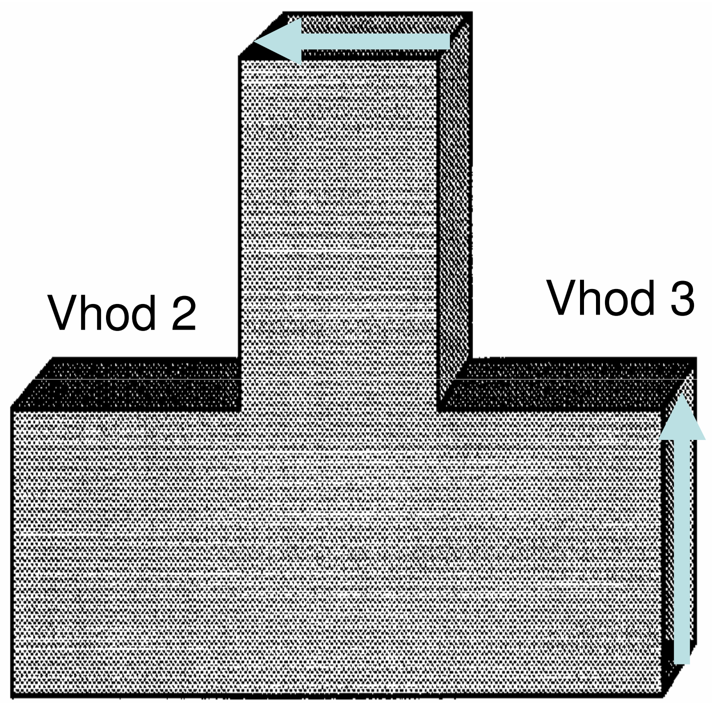
$$R2 = \frac{1}{\dfrac{10^{\frac{L}{10}} + 1}{Zout\left(10^{\frac{L}{10}} - 1\right)} - \dfrac{1}{R3}}$$

$$R1 = \frac{1}{\dfrac{10^{\frac{L}{10}} + 1}{Zin\left(10^{\frac{L}{10}} - 1\right)} - \dfrac{1}{R3}}$$

6- polna vezja



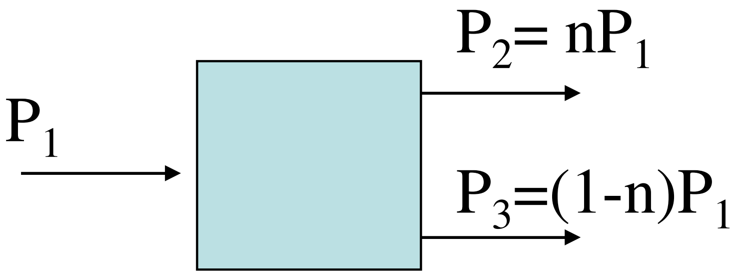
Trojnik v ravnini E



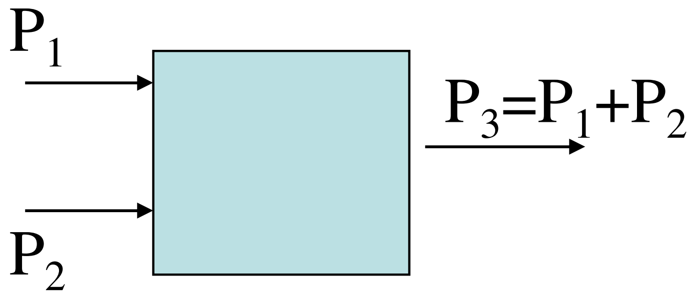
Trojnik v ravnini H

Delitev in združevanje moči

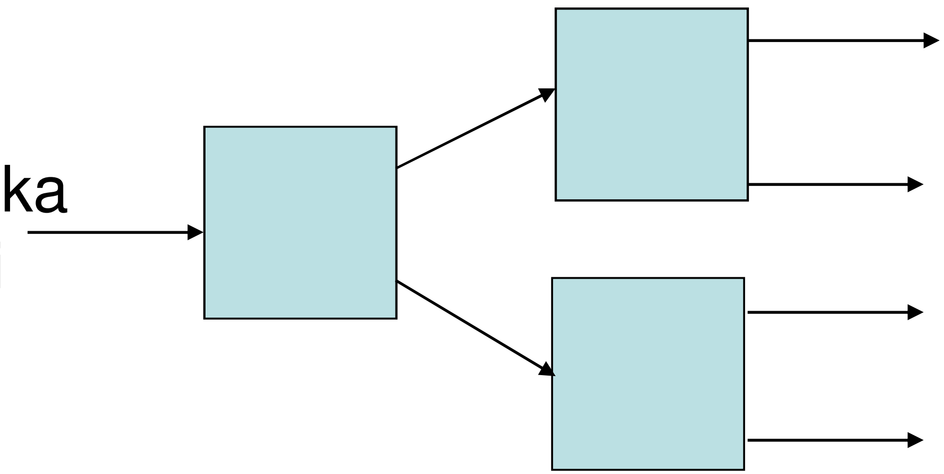
Delitev moči



Združevanje moči



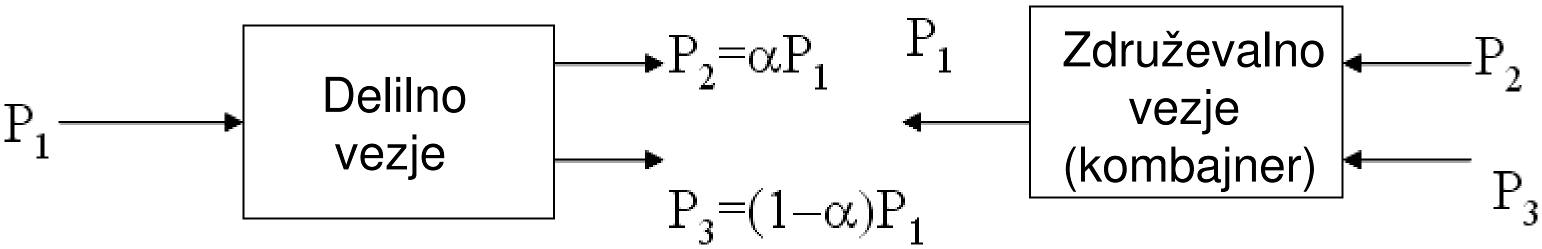
Dvostopenjska delitev moči



Delilniki in združevalniki moči so naprava, ki se uporablja zelo pogosto v radijskih omrežjih (oddajniki, antenski sistemi in drugo).

Delilna in združevalna vezja

1. notranje prilagojeno 2. recipročno 3. brez izgub



notranje prilagojeno in recipročno:

$$[S]=\begin{bmatrix} 0 & S_{12} & S_{13} \\ S_{12} & 0 & S_{23} \\ S_{13} & S_{23} & 0 \end{bmatrix}$$

brez izgub: X

$$[S][S]^{*T} = [1]$$

$$|S_{12}|^2+|S_{13}|^2=1 \quad , \quad |S_{12}|^2+|S_{23}|^2=1 \quad , \quad |S_{13}|^2+|S_{23}|^2=1$$

$$S_{13}^{*}S_{23}=0 \quad , \quad S_{23}^{*}S_{12}=0 \quad , \quad S_{12}^{*}S_{13}=0$$

Ugotovimo, da so enačbe med seboj protislovne, kar pomeni, da šestpolno vezje s predpostavljenimi lastnostmi ne obstaja. Vezje ne more imeti vseh treh lastnosti.

Unitarne enačbe 6- polnega vezja

Splošna matrika

1. Notranje neprilagojeno
2. Nerecipročno
3. Vezje brez izgub

$$[S]=\begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix}$$

$$\sum_{k=1}^{N} S_{ki} S_{ki}^{*} = 1$$

$$\sum_{k=1}^{N} S_{ki} S_{kj}^{*} = 0 \qquad for\; i \neq j$$

$$|S_{11}|^2 + |S_{21}|^2 + |S_{31}|^2 = 1$$

$$|S_{12}|^2 + |S_{22}|^2 + |S_{32}|^2 = 1$$

$$|S_{13}|^2 + |S_{23}|^2 + |S_{33}|^2 = 1$$

Produkt stolpca 1 in 2: $S_{11} S_{12}^{*} + S_{21} S_{22}^{*} + S_{31} S_{32}^{*} = 1$

Produkt stolpca 1 in 3: $S_{11} S_{13}^{*} + S_{21} S_{23}^{*} + S_{31} S_{33}^{*} = 1$

Produkt vrstice 2 in 3: $S_{12} S_{13}^{*} + S_{22} S_{23}^{*} + S_{32} S_{33}^{*} = 1$

Neobstoječe 6-polno vezje

1. Notranje prilagojeno: $S_{11} = S_{22} = S_{33} = 0$.
2. Recipročno: $S_{21} = S_{12}$; $S_{13} = S_{31}$; $S_{23} = S_{32}$.
3. Brez izgub: unitarnost matrike S.

Notranje prilagojeno in recipročno vezje:

$$[S] = \begin{bmatrix} 0 & S_{12} & S_{13} \\ S_{12} & 0 & S_{23} \\ S_{13} & S_{23} & 0 \end{bmatrix}$$

Vezje brez izgub, unitarnost:

$$|S_{12}|^2 + |S_{13}|^2 = 1 \qquad S_{13}^* S_{23} = 0$$

$$|S_{12}|^2 + |S_{23}|^2 = 1 \qquad S_{23}^* S_{12} = 0$$

$$|S_{13}|^2 + |S_{23}|^2 = 1 \qquad S_{12}^* S_{13} = 0$$

Dva izmed treh parametrov matrike (S_{12}, S_{13}, S_{23}) morata biti nič, če naj izpolnimo desne enačbe. S tem prekršimo leve enačbe. Če sta npr. $S_{12} = S_{13} = 0$, prekršimo obkroženo zgornjo enačbo. Pomeni, da takega vezja ni, teorija ga izključuje.

Cirkulator

1. Notranje prilagojeno 2. recipročno 3. brez izgub

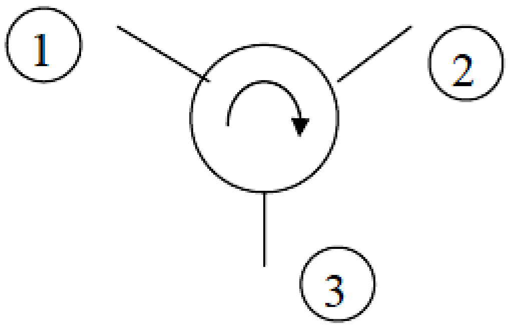
$$\begin{bmatrix} 0 & S_{12} & S_{13} \\ S_{12} & 0 & S_{23} \\ S_{13} & S_{23} & 0 \end{bmatrix} \rightarrow \begin{matrix} |S_{12}|^2 + |S_{13}|^2 = 1 & S_{13}^* S_{23} = 0 \\ |S_{12}|^2 + |S_{23}|^2 = 1 \, , & S_{12}^* S_{13} = 0 \rightarrow \text{if } S_{13} = 0, \\ |S_{13}|^2 + |S_{23}|^2 = 1 & S_{12}^* S_{23} = 0 \end{matrix} \quad \begin{matrix} |S_{12}| = 1 \\ |S_{23}| = 0 \quad \rightarrow \\ |S_{13}| = 1 \neq 0 \end{matrix}$$

1. Notranje prilagojeno 2. nerecipročno 3. brez izgub

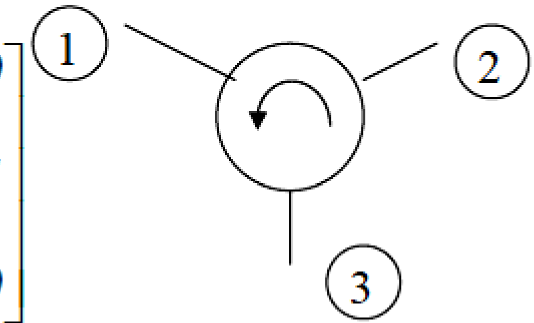
$$\begin{bmatrix} 0 & S_{12} & S_{13} \\ S_{21} & 0 & S_{23} \\ S_{31} & S_{32} & 0 \end{bmatrix} \rightarrow \begin{matrix} |S_{21}|^2 + |S_{31}|^2 = 1 & S_{31}^* S_{32} = 0 \\ |S_{12}|^2 + |S_{32}|^2 = 1 \, , & S_{12}^* S_{13} = 0 \rightarrow \\ |S_{13}|^2 + |S_{23}|^2 = 1 & S_{21}^* S_{23} = 0 \end{matrix}$$

$$\begin{matrix} \text{if } S_{21}=1 \rightarrow S_{31}=0, S_{32}=1, S_{23}=0, S_{13}=1, S_{12}=0 \\ \text{if } S_{21}=0 \rightarrow S_{31}=1, S_{32}=0, S_{23}=1, S_{13}=0, S_{12}=1 \end{matrix}$$

$$\begin{bmatrix} 0 & 0 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix}$$



$$\begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \end{bmatrix}$$



Cirkulator

1. Notranje prilagojeno: $S_{11} = S_{22} = S_{33} = 0$.
2. Nerecipročno: $S_{21} \neq S_{12}$; $S_{13} \neq S_{31}$; $S_{23} \neq S_{32}$.
3. Brez izgub: unitarnost matrike S.

Notranje prilagojeno:

$$[S] = \begin{bmatrix} 0 & S_{12} & S_{13} \\ S_{21} & 0 & S_{23} \\ S_{31} & S_{32} & 0 \end{bmatrix}$$

Brez izgub:

$$|S_{12}|^2 + |S_{13}|^2 = 1 \qquad S^*_{31} S_{32} = 0$$

$$|S_{21}|^2 + |S_{23}|^2 = 1 \qquad S^*_{21} S_{23} = 0$$

$$|S_{31}|^2 + |S_{32}|^2 = 1 \qquad S^*_{12} S_{13} = 0$$

1. rešitev:

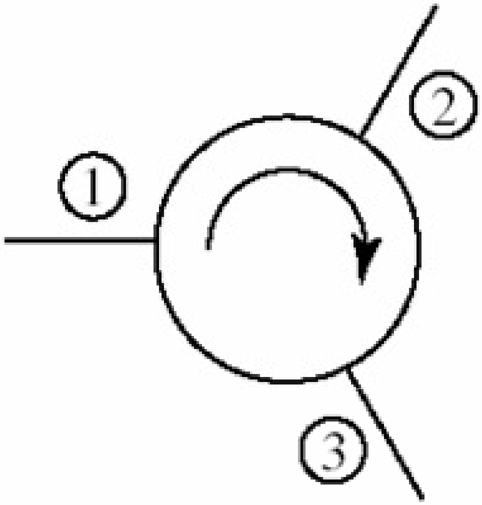
$$S_{12} = S_{23} = S_{31} = 0 \qquad |S_{21}| = |S_{32}| = |S_{13}| = 1$$

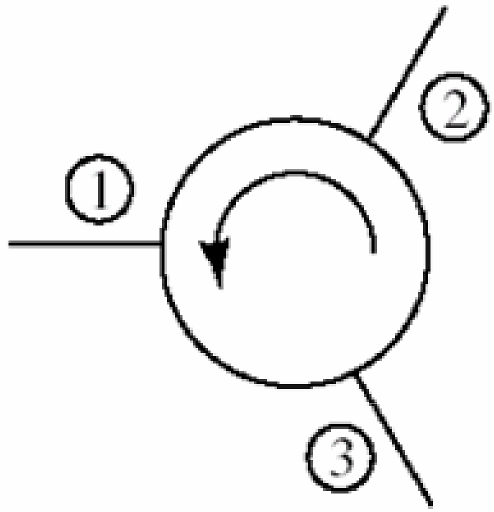
2. rešitev:

$$S_{21} = S_{32} = S_{13} = 0 \qquad |S_{12}| = |S_{23}| = |S_{31}| = 1$$

Obstajata dve rešitvi parametrov, ki predstavljata dve vrsti vezja, ki jima je skupno cirkuliranje signala.

Izolator





$$[S] = \begin{bmatrix} 0 & 0 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix} or \quad [S] = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \end{bmatrix}$$

Cirkulator, graf

Notranja prilagoditev

$$|S| = \begin{bmatrix} 0 & S_{12} & S_{13} \\ S_{21} & 0 & S_{23} \\ S_{31} & S_{32} & 0 \end{bmatrix}$$

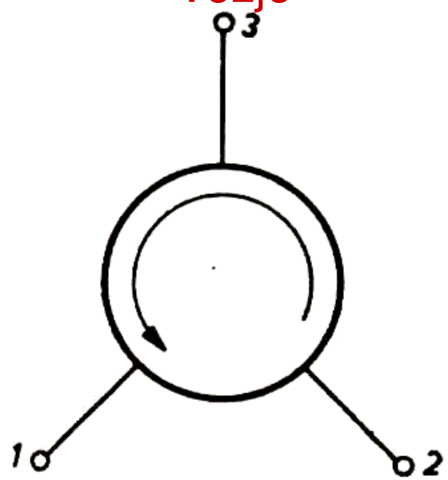
Brezizgubnost in nerecipročnost

$$|S_{21}|^2 + |S_{31}|^2 = 1,$$
$$|S_{12}|^2 + |S_{32}|^2 = 1,$$
$$|S_{13}|^2 + |S_{23}|^2 = 1,$$
$$S_{31}S_{32}^* = S_{12}S_{13}^* = S_{21}S_{23}^* = 0.$$

Matrika

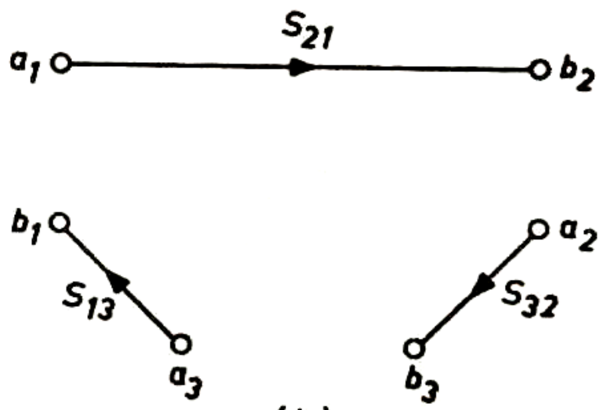
$$|S| = \begin{bmatrix} 0 & 0 & S_{13} \\ S_{21} & 0 & 0 \\ 0 & S_{32} & 0 \end{bmatrix}$$

Vezje



(a)

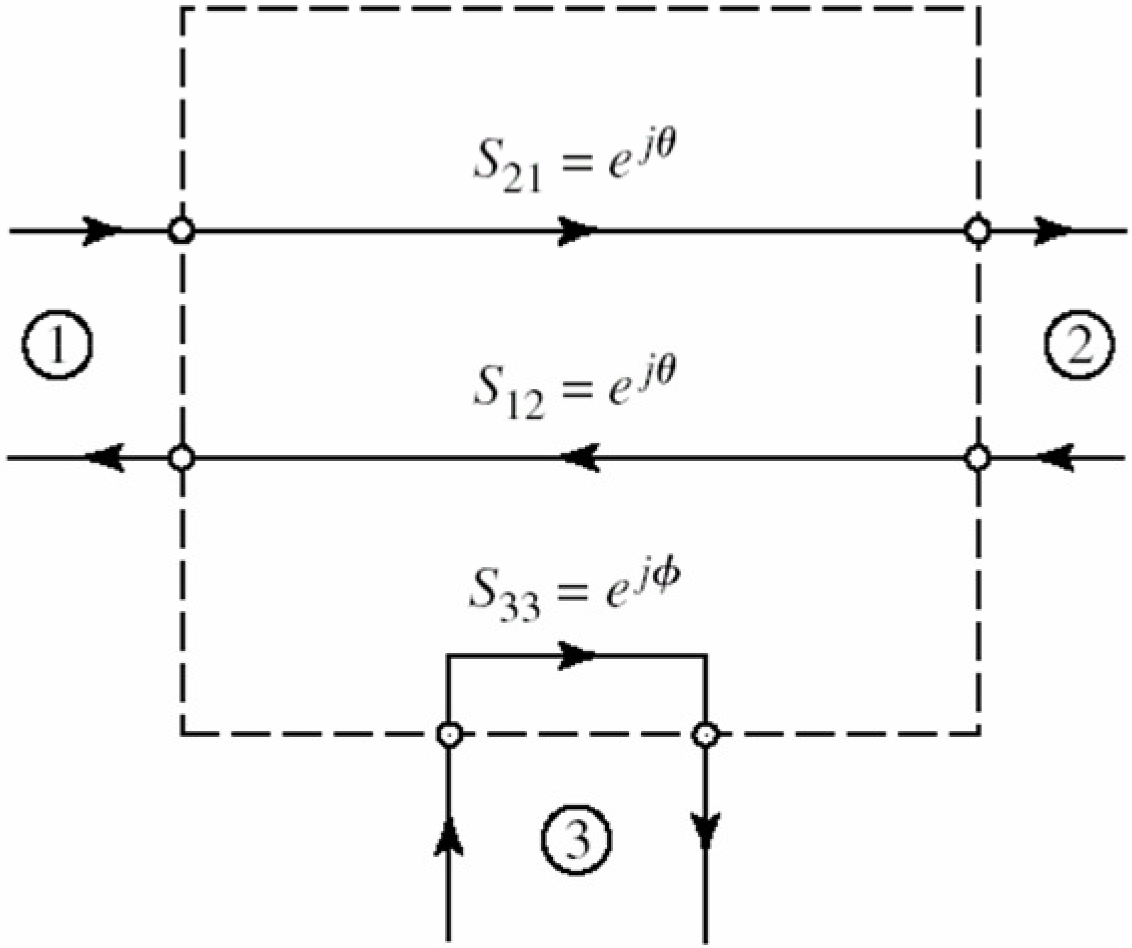
Smerni graf



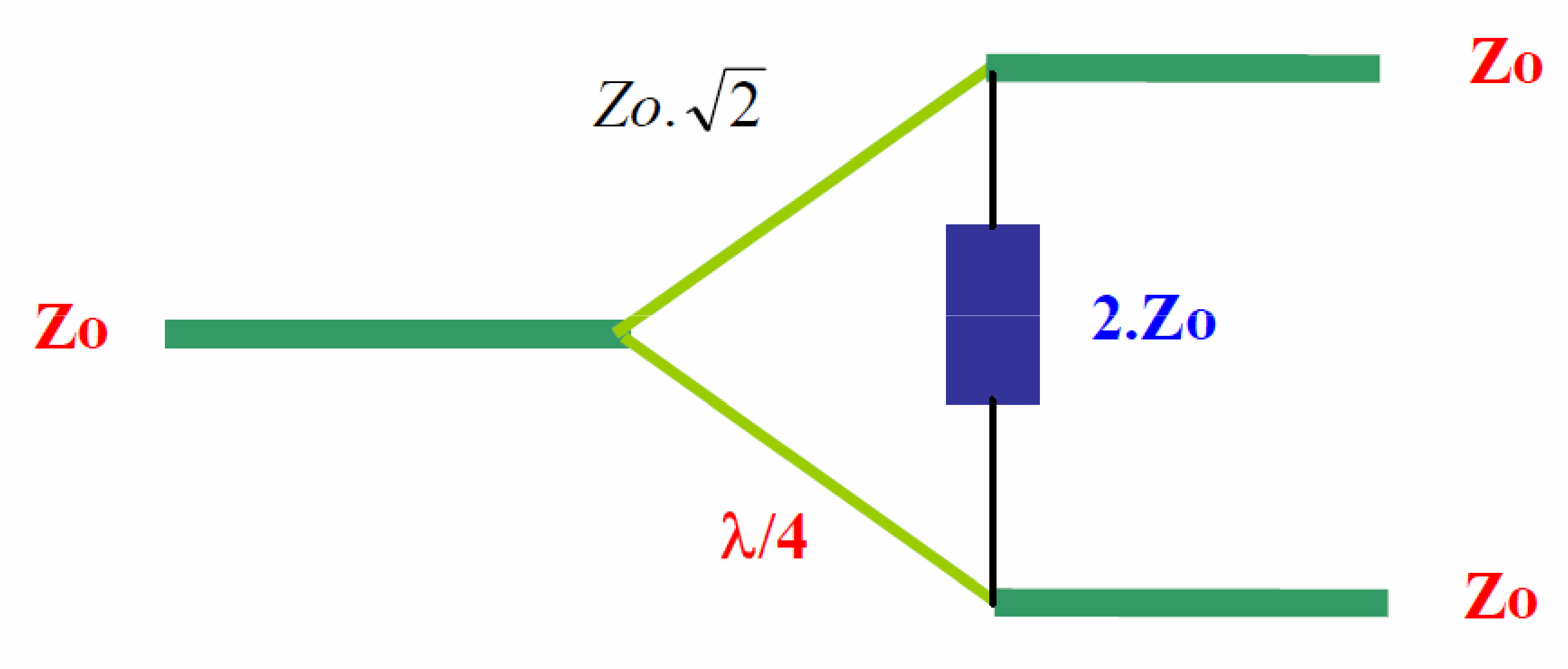
(b)

Smerni graf cirkulatorja

$$[S] = \begin{bmatrix} 0 & e^{j\theta} & 0 \\ e^{j\theta} & 0 & 0 \\ 0 & 0 & e^{j\phi} \end{bmatrix}$$

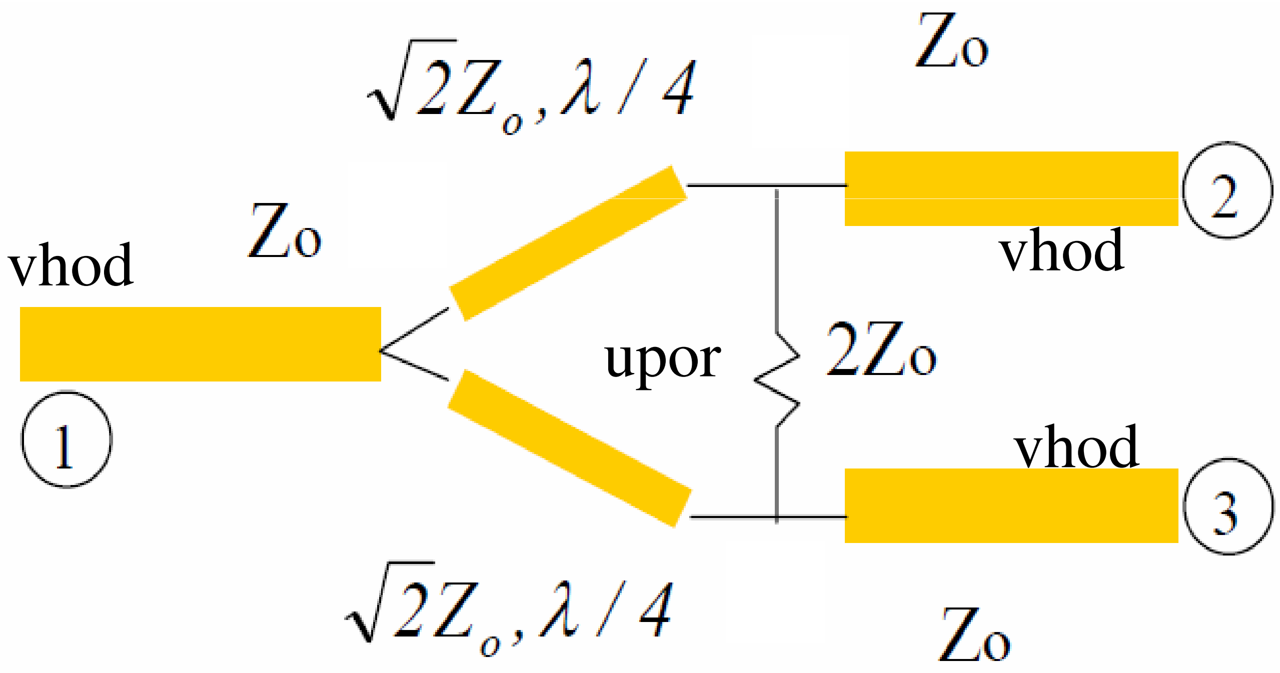


Wilkinsonov delilnik moči



Wilkinsonov delilnik moči

1. Notranje prilagojeno
2. recipročno
3. vezje z izgubami (upornost $2Z_0$)



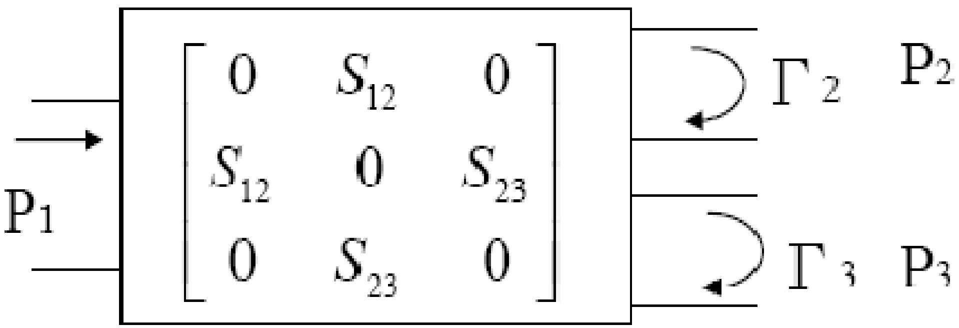
Matrika

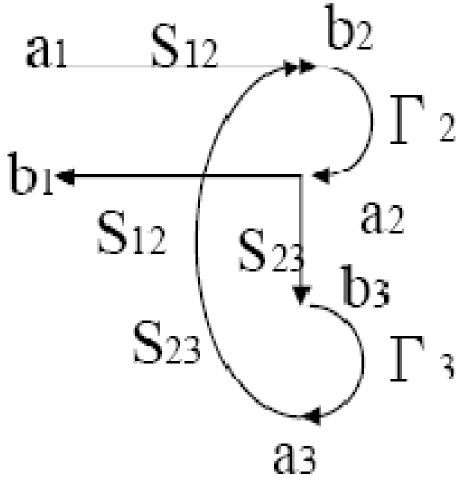
$$\frac{1}{\sqrt{2}}\begin{bmatrix} 0 & -j & -j \\ -j & 0 & 0 \\ -j & 0 & 0 \end{bmatrix}$$

Vhoda 2 in 3 sta izolirana ($S_{32} = S_{23} = 0$)

Delilno razmerje moči 6- polnega vezja

Prob. 4.30 find P2/P1 and P3/P1





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

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

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

Moč P3 je sorazmerna odbojnosti Γ_2

Neprilagojeno 6- polno vezje

1. Notranje neprilagojeno (na vhodu 3-3)
2. Recipročno
3. Brez izgub

Neprilagojeno na 3-3
Recipročno

$$[S]=\begin{bmatrix} 0 & S_{12} & S_{13} \\ S_{12} & 0 & S_{23} \\ S_{13} & S_{23} & S_{33} \end{bmatrix}$$

Vezje brez izgub, unitarnost matrike [S]

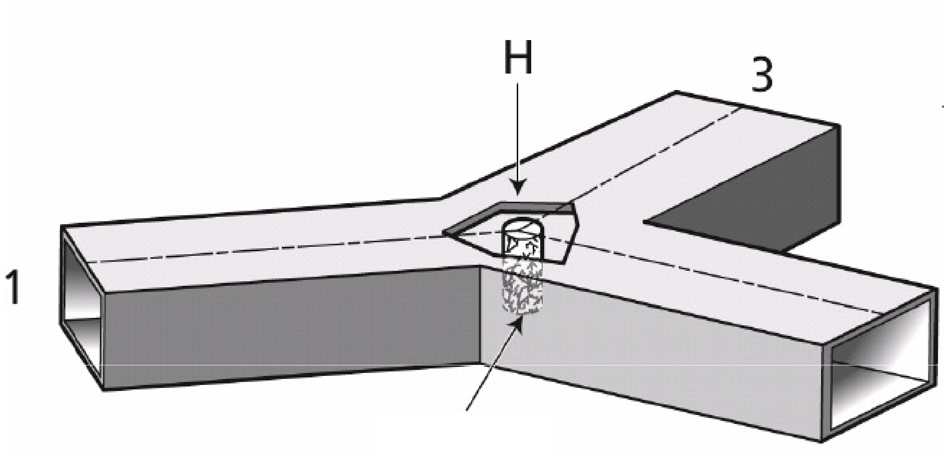
$$|S_{12}|^2+|S_{13}|^2=1 \qquad S_{13}^{*}S_{23}=0$$

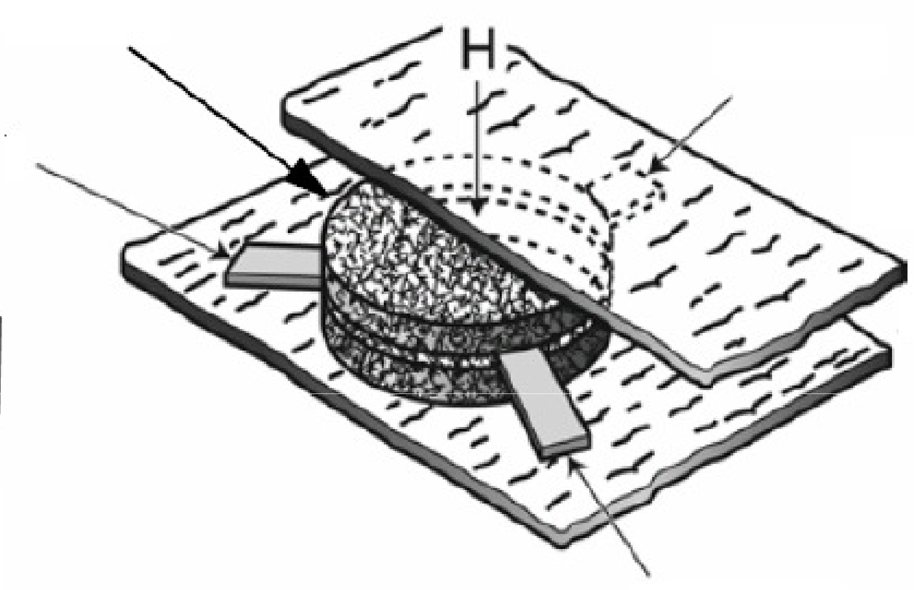
$$|S_{12}|^2+|S_{23}|^2=1 \qquad S_{12}^{*}S_{13}+S_{23}^{*}S_{33}=0$$

$$|S_{13}|^2+|S_{23}|^2+|S_{33}|^2=1 \qquad S_{23}^{*}S_{12}+S_{33}^{*}S_{13}=0$$

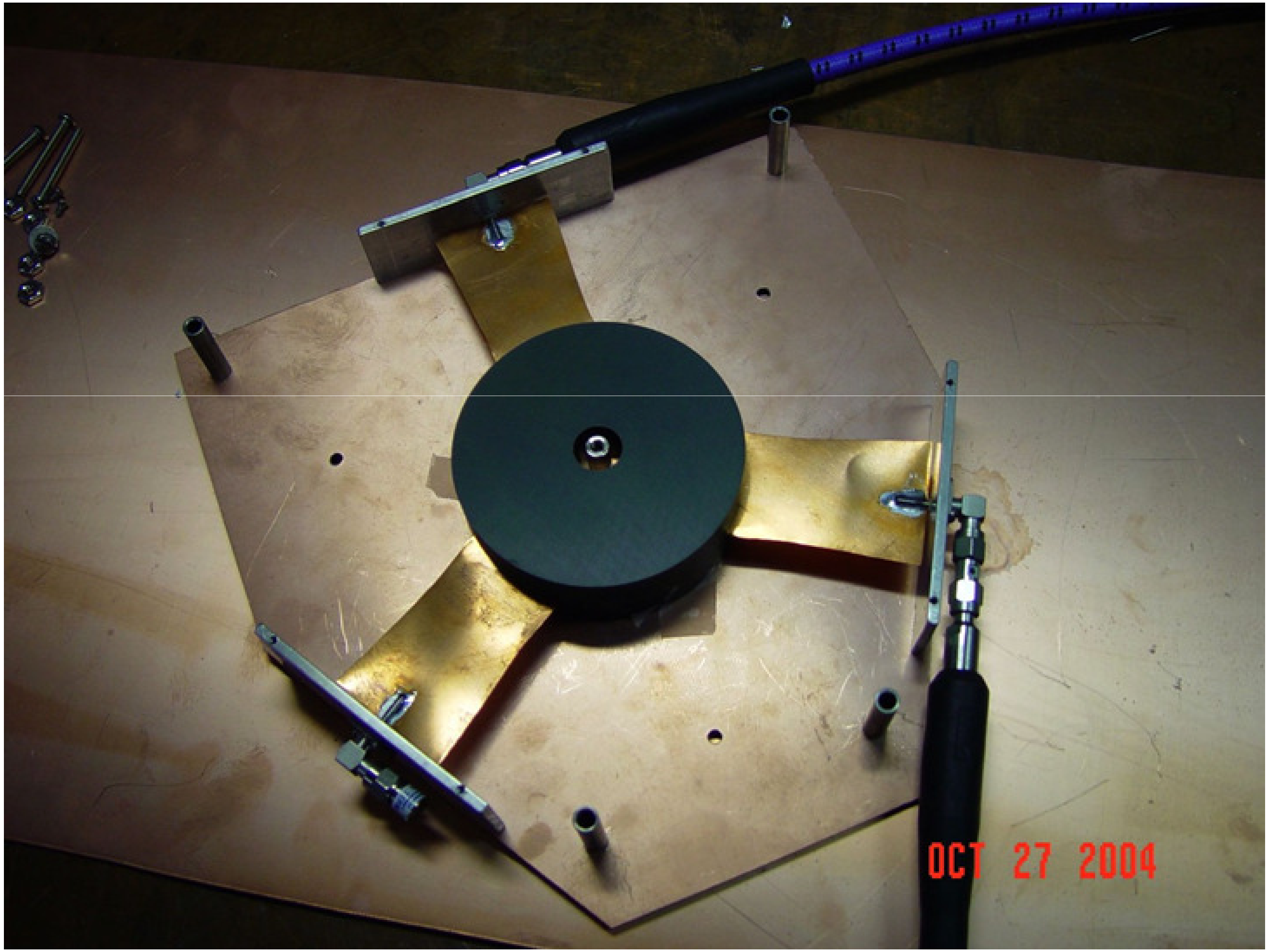
Iz prve in druge leve enačbe sledi $|S_{13}| = |S_{23}|$, zato je $S_{13} = S_{23} = 0$. Iz levih enačb sledi še $|S_{12}| = |S_{33}| = 1$.

Valovodni in planarni cirkulator

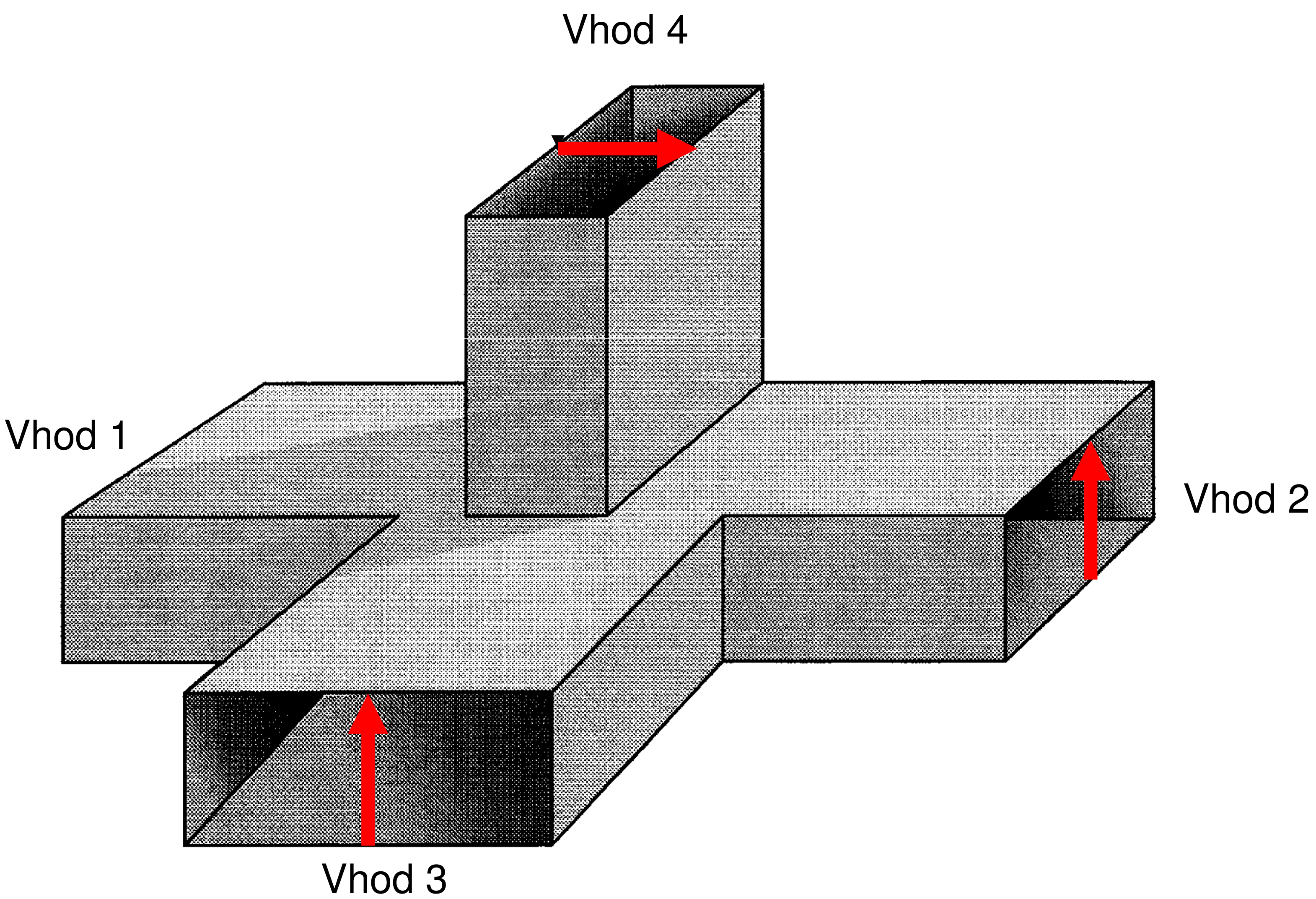




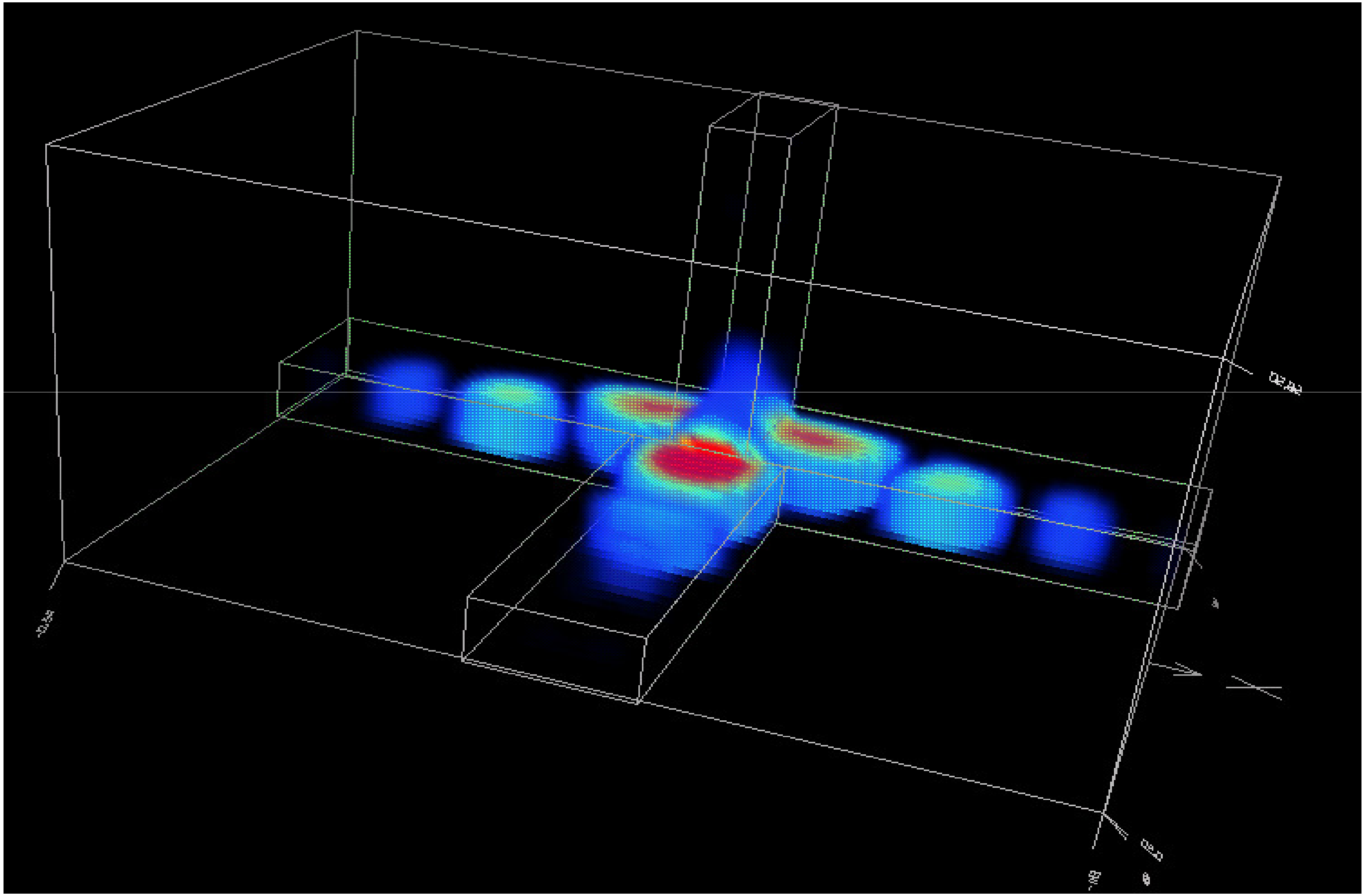
Prototipni cirkulator



8-polna hibridna vezja –valovodni magični T

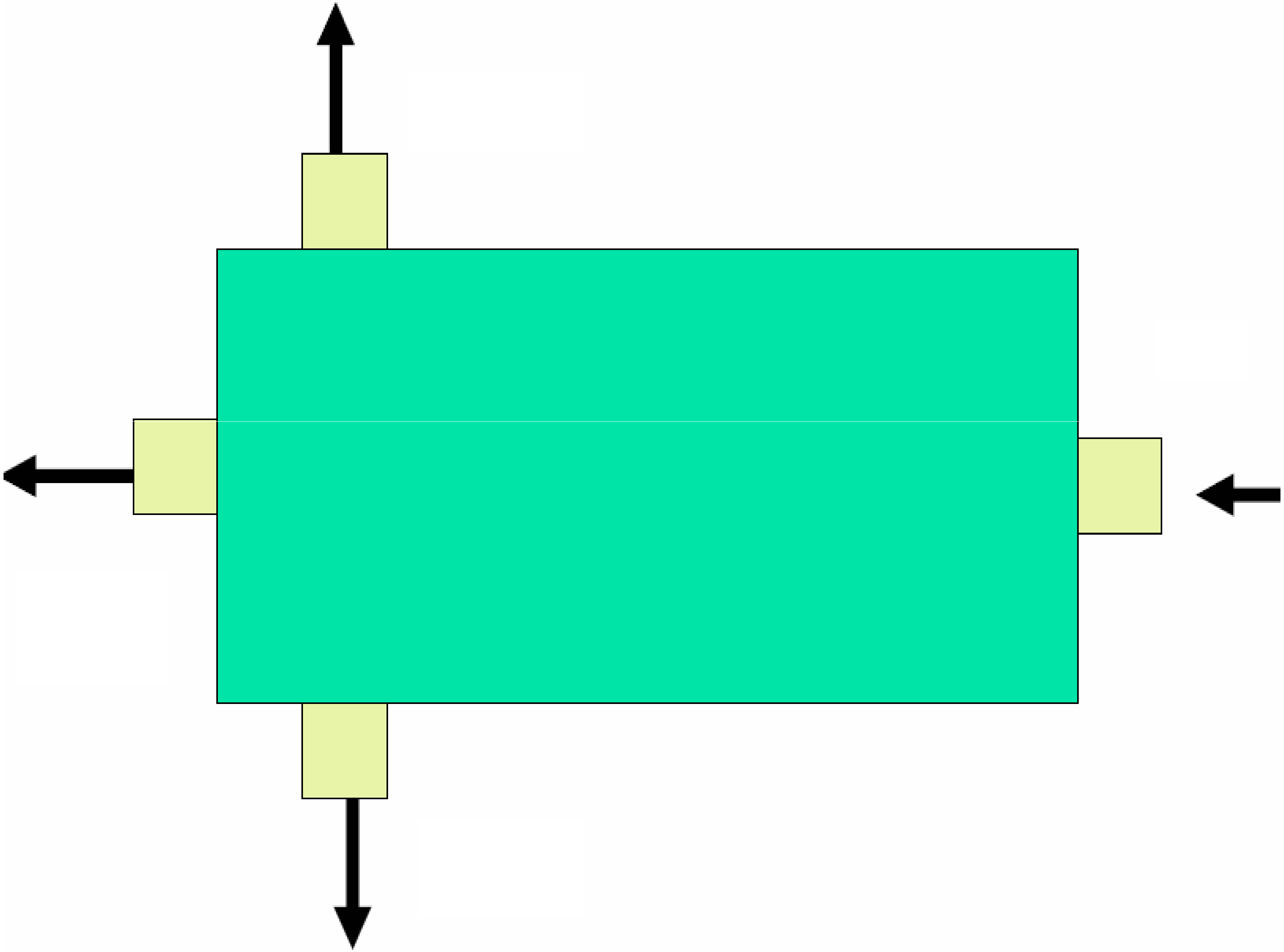


Polje v razvejišču



Polje iz vhoda 3 se sklaplja na vhod 1 in 2 ter se ne sklaplja na vhod 4.

Večvhodna vezja



8- polno vezje

1. Notranje prilagojeno
2. Recipročno
3. Brez izgub

$$[S]=\begin{bmatrix} 0 & S_{12} & S_{13} & S_{14} \\ S_{12} & 0 & S_{23} & S_{24} \\ S_{13} & S_{23} & 0 & S_{34} \\ S_{14} & S_{24} & S_{34} & 0 \end{bmatrix}$$

Pogoji, ki izhajajo iz unitarnosti matrike S:

$$|S_{12}|+|S_{13}|+|S_{14}|=1$$

$$|S_{12}|+|S_{23}|+|S_{24}|=1$$

$$|S_{13}|+|S_{23}|+|S_{34}|=1$$

$$|S_{14}|+|S_{24}|+|S_{34}|=1$$

$$S_{13}S_{23}^{*}+S_{14}S_{24}^{*}=0$$

$$S_{12}S_{23}^{*}+S_{14}S_{34}^{*}=0$$

$$S_{12}S_{24}^{*}+S_{13}S_{34}^{*}=0$$

$$S_{12}S_{13}^{*}+S_{24}S_{34}^{*}=0$$

$$S_{12}S_{14}^{*}+S_{23}S_{34}^{*}=0$$

$$S_{13}S_{14}^{*}+S_{23}S_{24}^{*}=0$$

8- polno vezje

1. Notranje prilagojeno
2. Recipročno
3. Brez izgub

$$[S] = \begin{bmatrix} 0 & S_{12} & S_{13} & S_{14} \\ S_{12} & 0 & S_{23} & S_{24} \\ S_{13} & S_{23} & 0 & S_{34} \\ S_{14} & S_{24} & S_{34} & 0 \end{bmatrix}$$

$$\Rightarrow S_{13}^* S_{23} + S_{14}^* S_{24} = 0 \quad , \quad S_{14}^* S_{13} + S_{24}^* S_{23} = 0$$

$$S_{12}^* S_{23} + S_{14}^* S_{34} = 0 \qquad S_{14}^* S_{12} + S_{34}^* S_{23} = 0 \Rightarrow$$

$$S_{14}^* \left(\left| S_{13} \right|^2 - \left| S_{24} \right|^2 \right) = 0 \qquad S_{23} \left(\left| S_{12} \right|^2 - \left| S_{34} \right|^2 \right) = 0$$

$$S_{14} = S_{23}$$

Hibridni sklopniki 3 dB

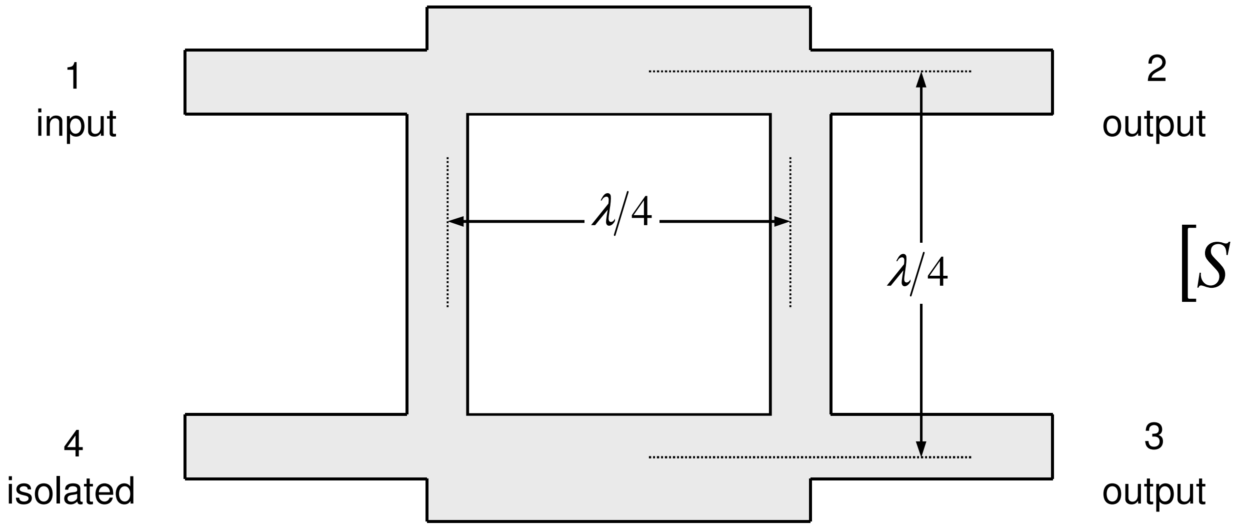
1. Kvadraturni hibrid
- 90^0 fazni zasuk

$$[S]=\frac{1}{\sqrt{2}}\begin{bmatrix} 0 & 1 & j & 0 \\ 1 & 0 & 0 & j \\ j & 0 & 0 & 1 \\ 0 & j & 1 & 0 \end{bmatrix}$$

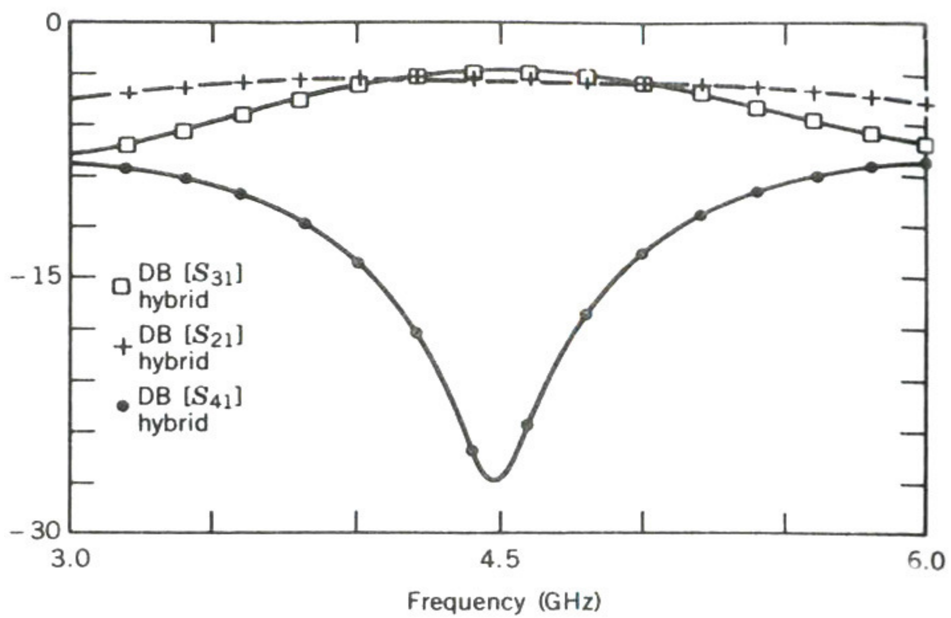
2. Hibrid Magični T
- 180^0 fazni zasuk

$$[S]=\frac{1}{\sqrt{2}}\begin{bmatrix} 0 & 1 & 1 & 0 \\ 1 & 0 & 0 & -1 \\ 1 & 0 & 0 & 1 \\ 0 & -1 & 1 & 0 \end{bmatrix}$$

Hibridni 3 dB sklopnik



$$[S] = \frac{-1}{\sqrt{2}} \begin{bmatrix} 0 & j & 1 & 0 \\ j & 0 & 0 & 1 \\ 1 & 0 & 0 & j \\ 0 & 1 & j & 0 \end{bmatrix}$$

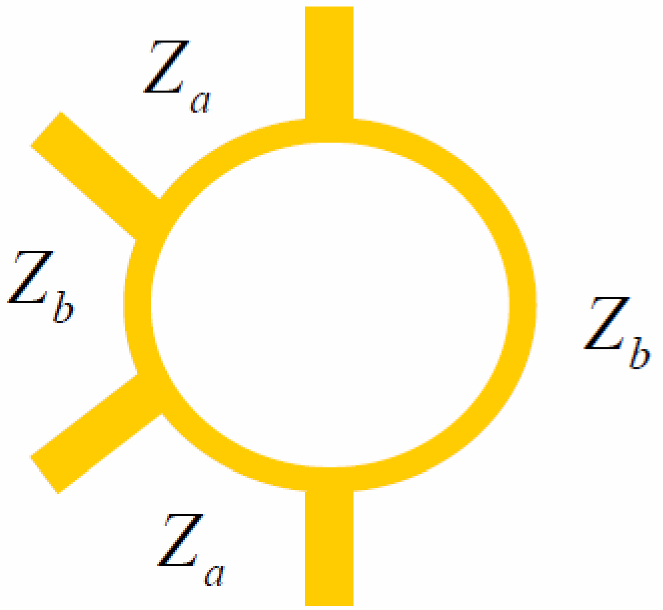


- delilnik moči
- fazni obračalnik 90^0

Obročni hibrid

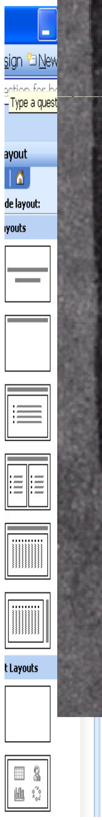
$$\begin{bmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \end{bmatrix} = -\frac{j}{\sqrt{2}} \begin{bmatrix} 0 & 1 & 1 & 0 \\ 1 & 0 & 0 & -1 \\ 1 & 0 & 0 & 1 \\ 0 & -1 & 1 & 0 \end{bmatrix} \begin{bmatrix} 0 \\ a_2 \\ a_3 \\ 0 \end{bmatrix} = -\frac{j}{\sqrt{2}} \begin{bmatrix} a_2 + a_3 \\ 0 \\ 0 \\ -a_2 + a_3 \end{bmatrix}$$

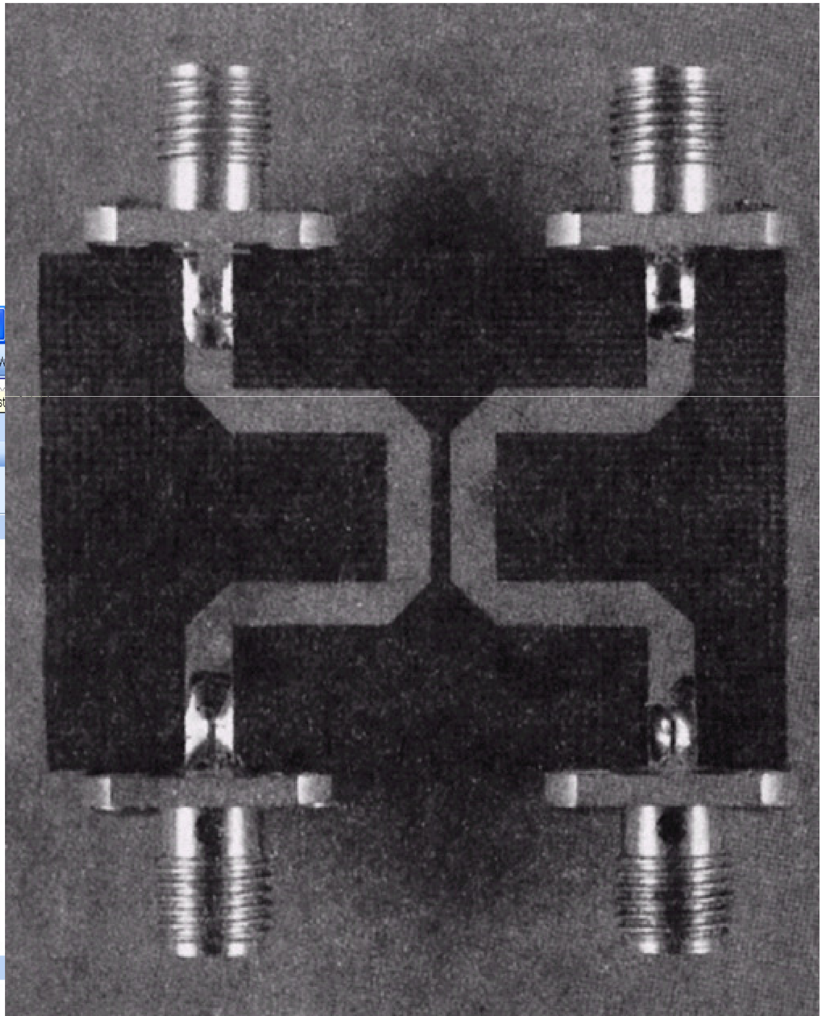
Dolžine:
$\lambda/4$, $\lambda/4$, $\lambda/4$
$3\lambda/4$



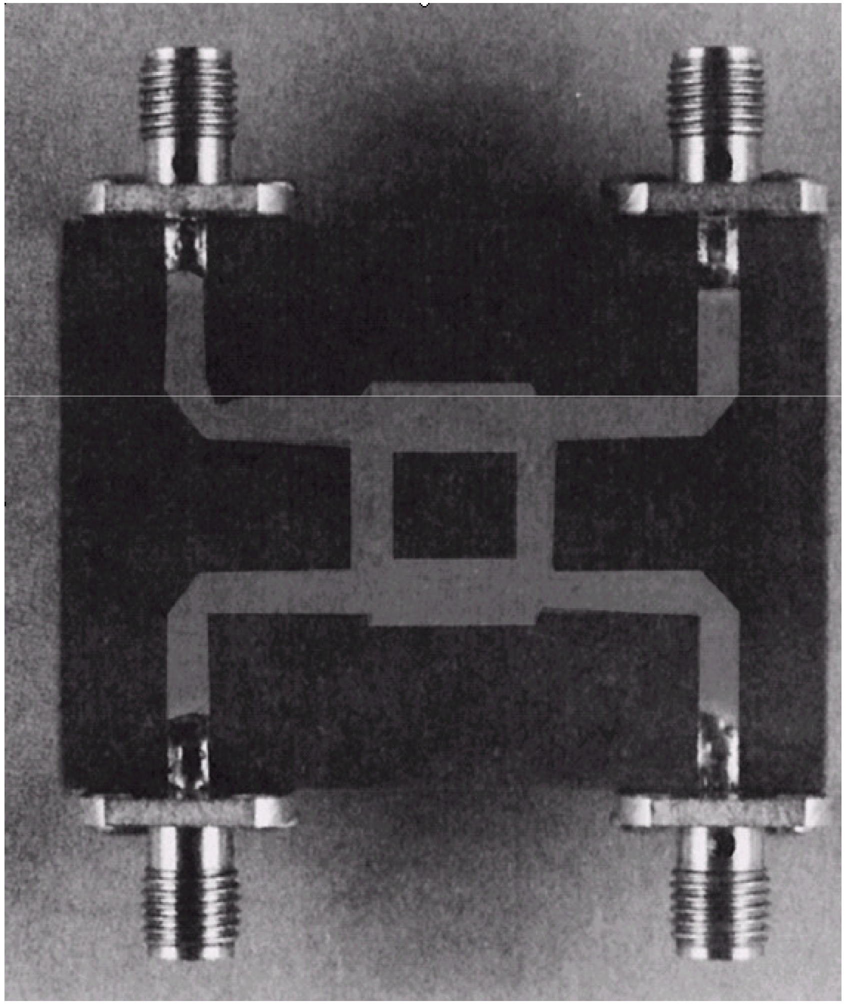
Sklopnik in kvadratni hibrid

Trakasti sklopnik

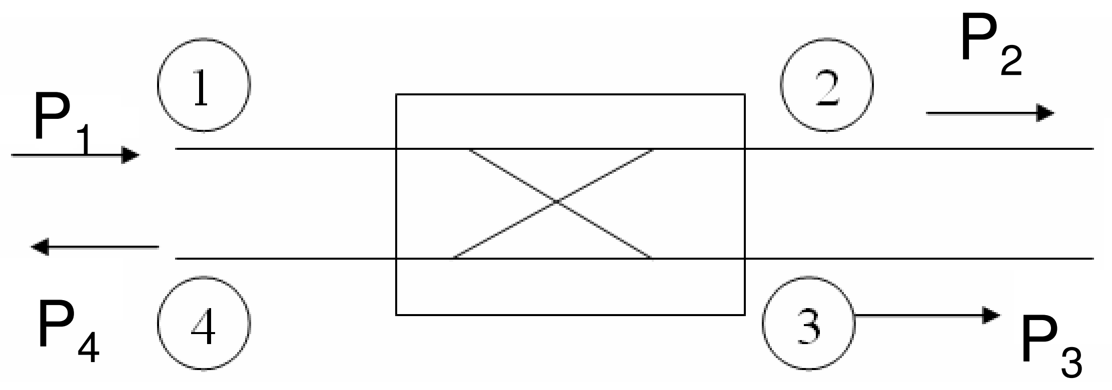




Trakasti kvadratni hibrid



Karakteristike smernega sklopnika



I = D + C

Sklopno razmerje: $$C = 10\log\frac{P_1}{P_3} = -20\log\beta \ \ \text{dB}$$

Smernost: $$D = 10\log\frac{P_3}{P_4} = 20\log\frac{\beta}{|S_{14}|}\text{dB}$$

Izolacija: $$I = 10\log\frac{P_1}{P_4} = -20\log|S_{14}| \ \ \text{dB}$$

Matrike 8- polnih vezij, pregled

1. Notranje prilagojena 2. recipročna 3. brez izgub

sklopnik 90^0

$$\begin{bmatrix} 0 & \alpha & j\beta & 0 \\ \alpha & 0 & 0 & j\beta \\ j\beta & 0 & 0 & \alpha \\ 0 & j\beta & \alpha & 0 \end{bmatrix}$$

sklopnik 180^0

$$\begin{bmatrix} 0 & \alpha & \beta & 0 \\ \alpha & 0 & 0 & -\beta \\ \beta & 0 & 0 & \alpha \\ 0 & -\beta & \alpha & 0 \end{bmatrix}$$

3-dB 90^0 kvadratni hibrid

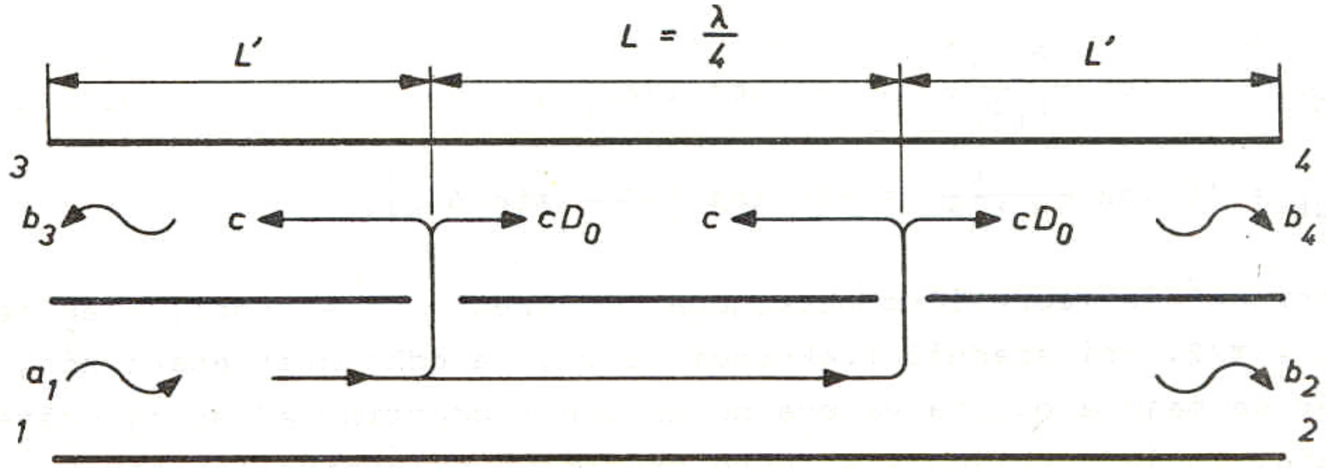
$$\frac{1}{\sqrt{2}}\begin{bmatrix} 0 & 1 & j & 0 \\ 1 & 0 & 0 & j \\ j & 0 & 0 & 1 \\ 0 & j & 1 & 0 \end{bmatrix}$$

3-dB 180^0 hibrid (magični T, obroč)

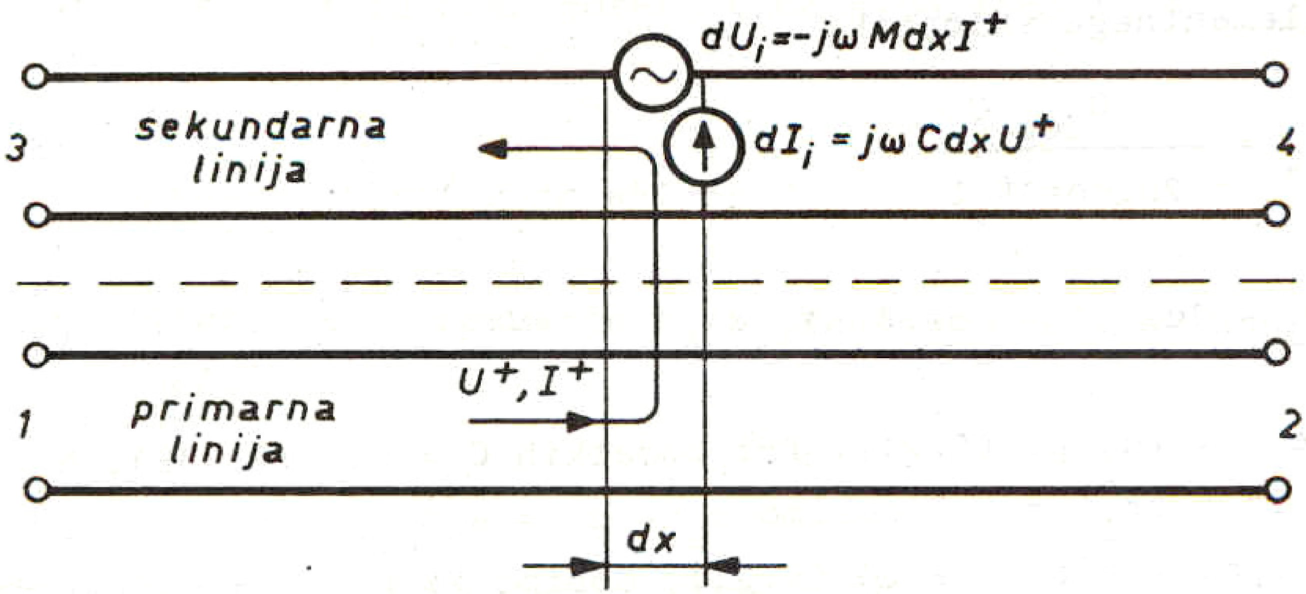
$$\frac{1}{\sqrt{2}}\begin{bmatrix} 0 & 1 & 1 & 0 \\ 1 & 0 & 0 & -1 \\ 1 & 0 & 0 & 1 \\ 0 & -1 & 1 & 0 \end{bmatrix}$$

Usmerjen električni in elektromagnetni sklop

Diskreten
električni
sklop



Porazdeljen
elektromag-
netni sklop



8- polno vezje

1. Notranje prilagojeno
2. Recipročno
3. Brez izgub

$$[S]=\begin{bmatrix} 0 & S_{12} & S_{13} & S_{14} \\ S_{12} & 0 & S_{23} & S_{24} \\ S_{13} & S_{23} & 0 & S_{34} \\ S_{14} & S_{24} & S_{34} & 0 \end{bmatrix}$$

Pogoji, ki izhajajo iz unitarnosti matrike S:

$$|S_{12}|+|S_{13}|+|S_{14}|=1$$

$$|S_{12}|+|S_{23}|+|S_{24}|=1$$

$$|S_{13}|+|S_{23}|+|S_{34}|=1$$

$$|S_{14}|+|S_{24}|+|S_{34}|=1$$

$$S_{13}S_{23}^{*}+S_{14}S_{24}^{*}=0$$

$$S_{12}S_{23}^{*}+S_{14}S_{34}^{*}=0$$

$$S_{12}S_{24}^{*}+S_{13}S_{34}^{*}=0$$

$$S_{12}S_{13}^{*}+S_{24}S_{34}^{*}=0$$

$$S_{12}S_{14}^{*}+S_{23}S_{34}^{*}=0$$

$$S_{13}S_{14}^{*}+S_{23}S_{24}^{*}=0$$

Sklopniki

Hybrid 3 dB couplers

$\theta = \varphi = \pi/2$

$\alpha = \beta = 1/\sqrt{2}$

$$[S] = \frac{1}{\sqrt{2}} \begin{bmatrix} 0 & 1 & j & 0 \\ 1 & 0 & 0 & j \\ j & 0 & 0 & 1 \\ 0 & j & 1 & 0 \end{bmatrix}$$

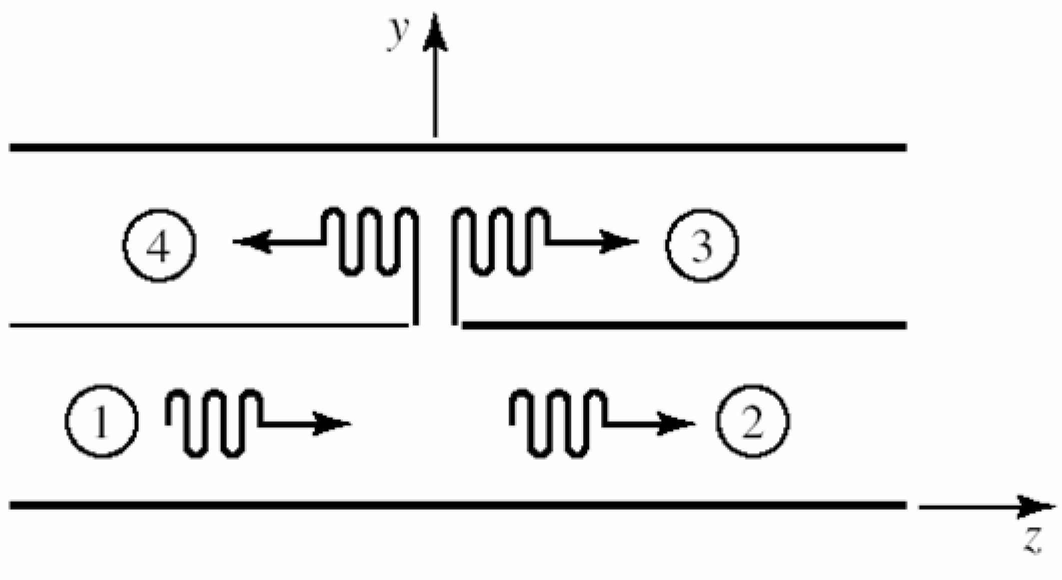
Magic -T and Rat-race couplers

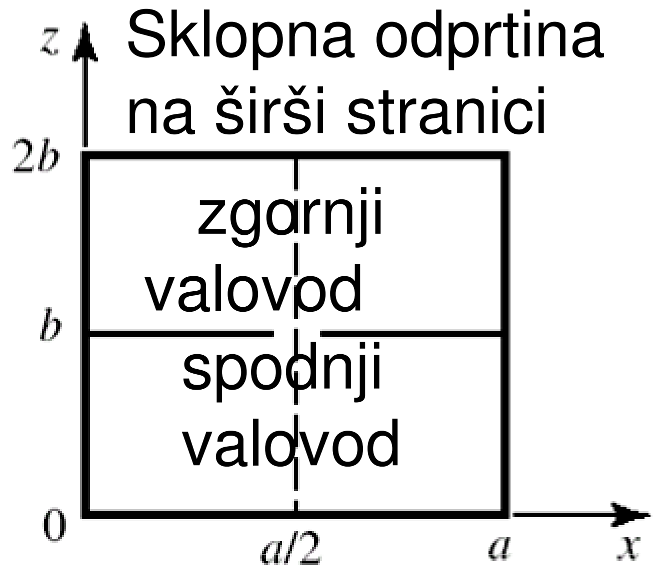
$\theta = 0, \varphi = \pi$

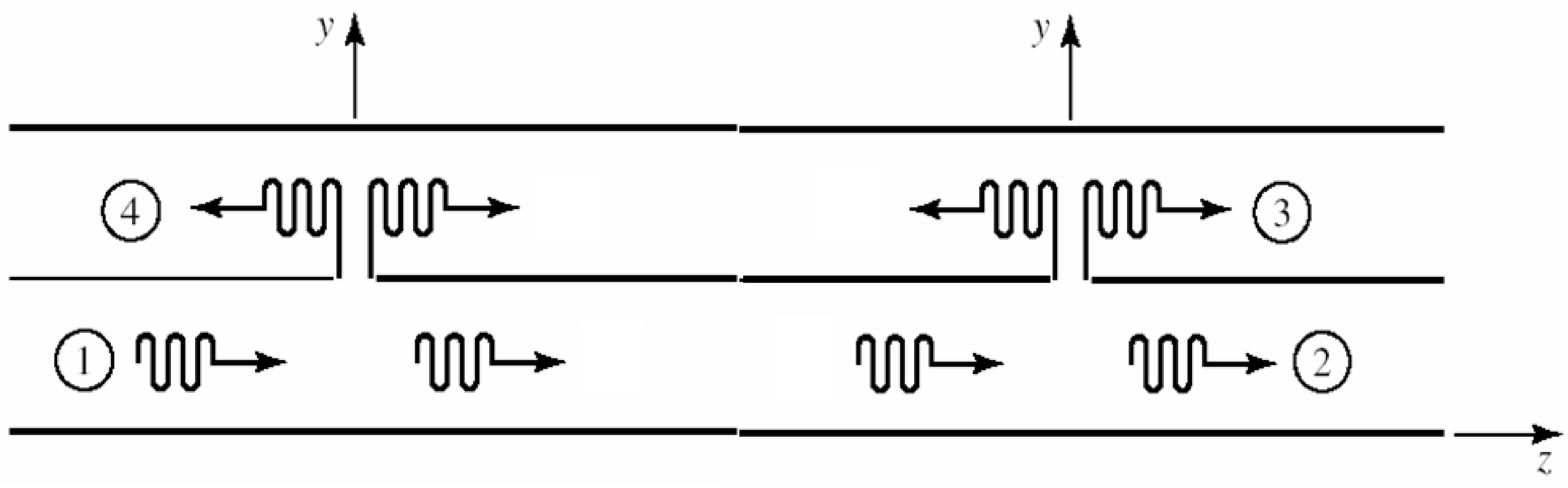
$\alpha = \beta = 1/\sqrt{2}$

$$[S] = \frac{1}{\sqrt{2}} \begin{bmatrix} 0 & 1 & 1 & 0 \\ 1 & 0 & 0 & -1 \\ 1 & 0 & 0 & 1 \\ 0 & -1 & 1 & 0 \end{bmatrix}$$

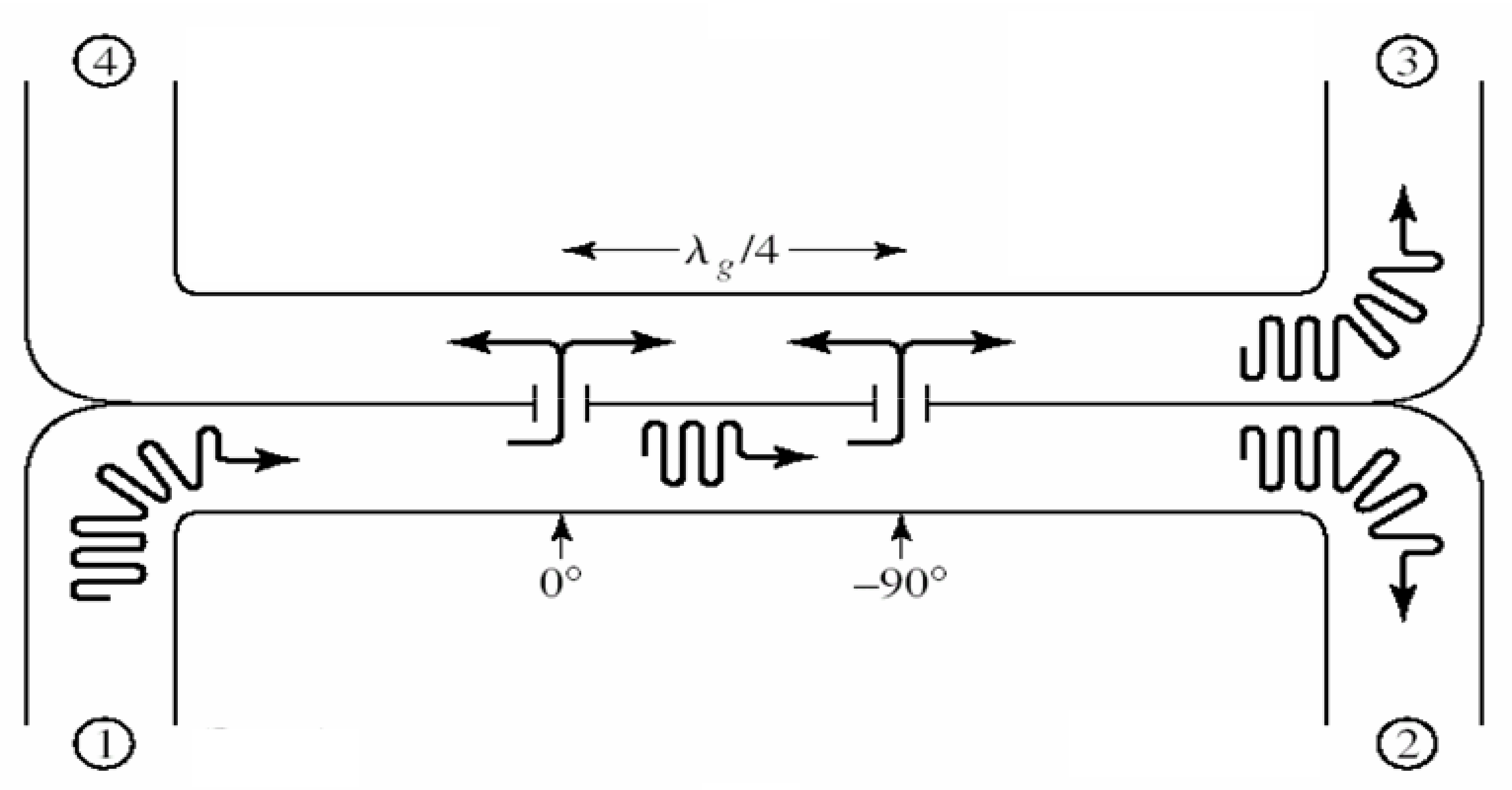
Sklopnik s sklopnima odprtinama





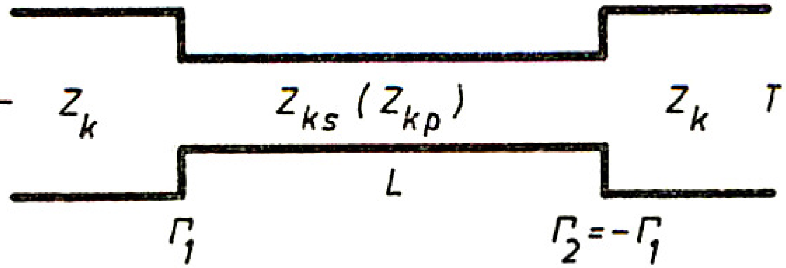


Sklopnik z odprtinama



Eno- in večstopenjski smerni sklopnik

$$\Gamma = \frac{\Gamma_1 (1 - e^{-j\beta 2L})}{1 - \Gamma_1^2 e^{-j\beta 2L}}$$



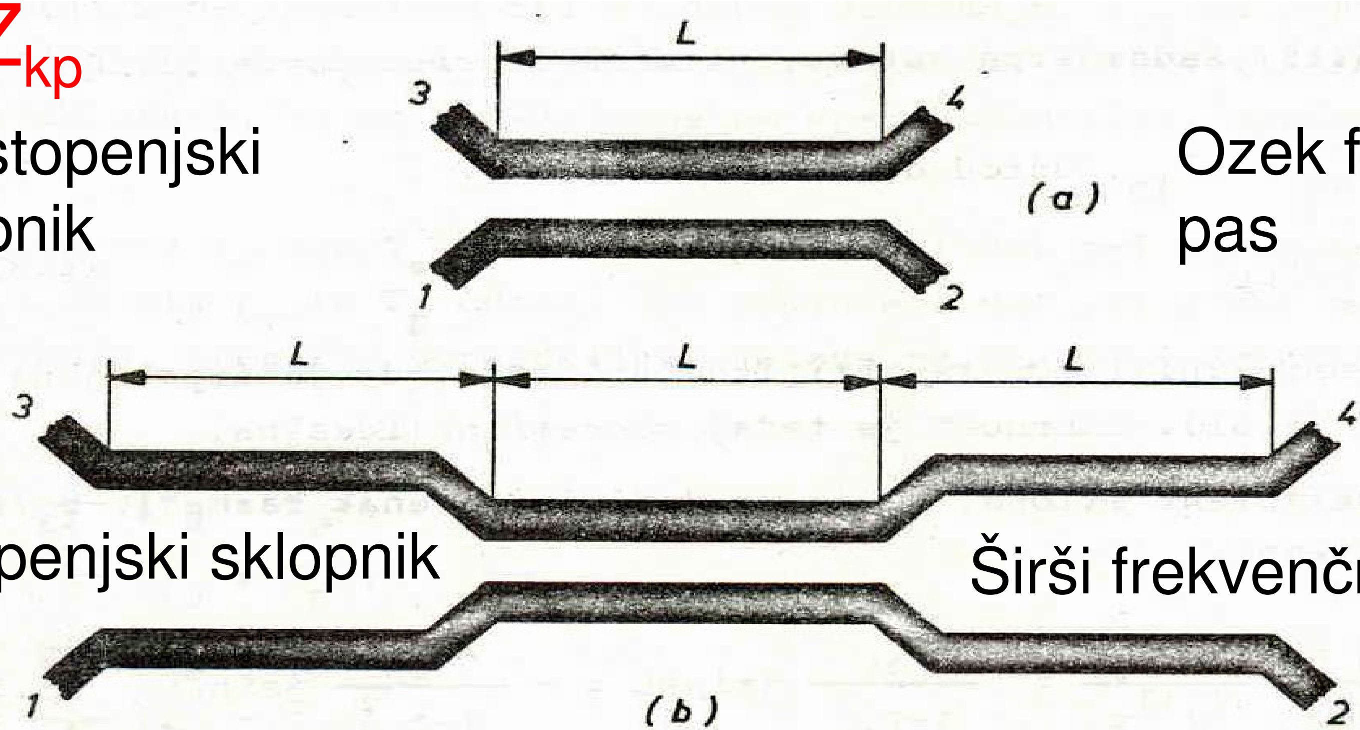
$$T = \frac{(1 - \Gamma_1^2) e^{-j\beta L}}{1 - \Gamma_1^2 e^{-j\beta 2L}}$$

$$\Gamma_{1s} = \frac{Z_{ks} - Z_k}{Z_{ks} + Z_k}, \quad \Gamma_{1p} = \frac{Z_{kp} - Z_k}{Z_{kp} + Z_k}$$

Pogoj za smernosr sklopnika $Z_k^2 = Z_{ks} Z_{kp}$

Enostopenjski sklopnik

Ozek frekvenčni pas

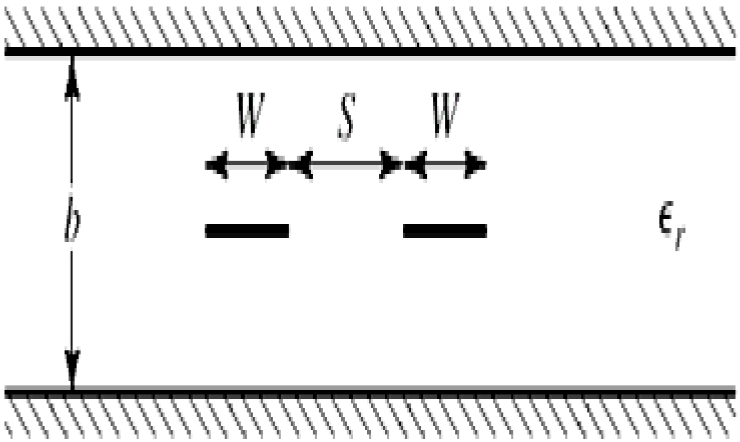


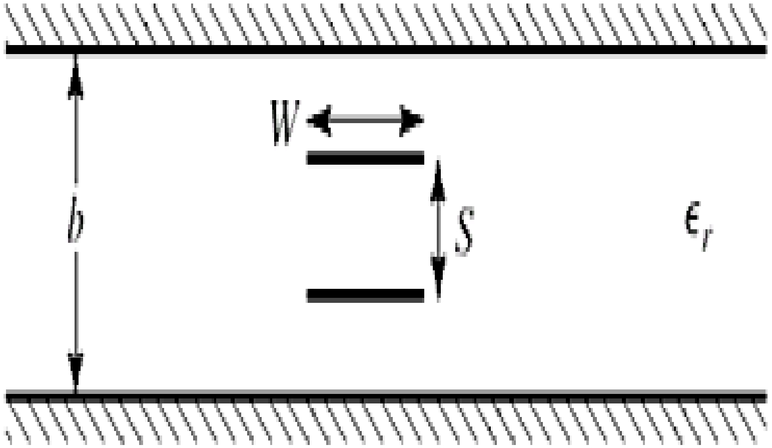
Tristopenjski sklopnik

Širši frekvenčni pas

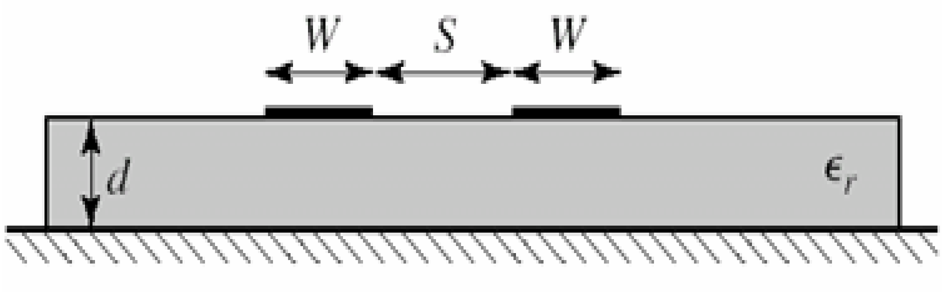
Trakasti in mikrotrakasti vodniki sklopnika

Trakasti vodniki

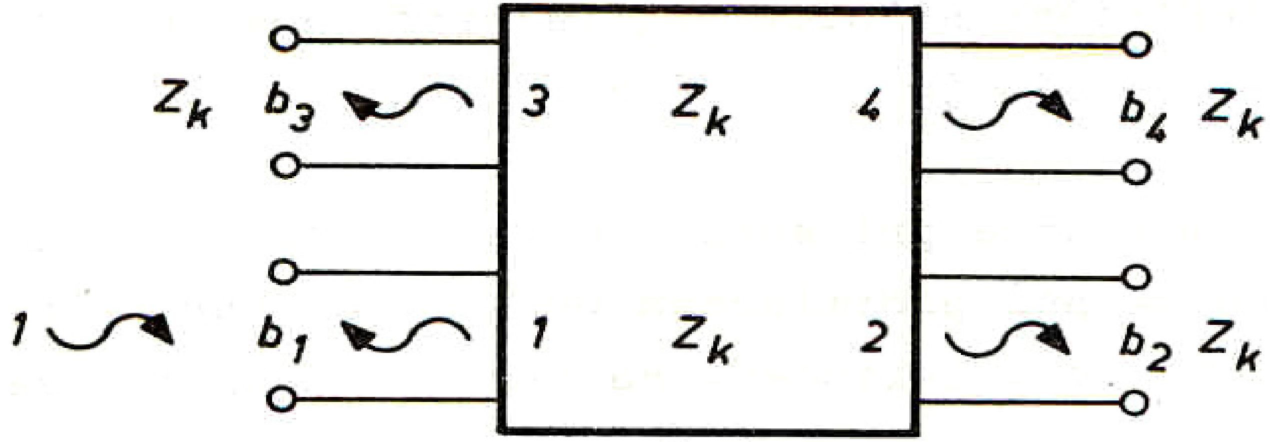




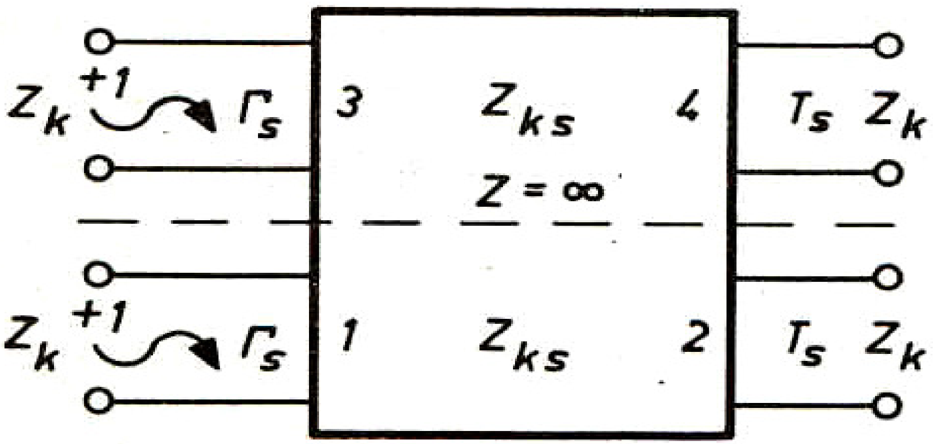
Mikrotrakasti vodniki



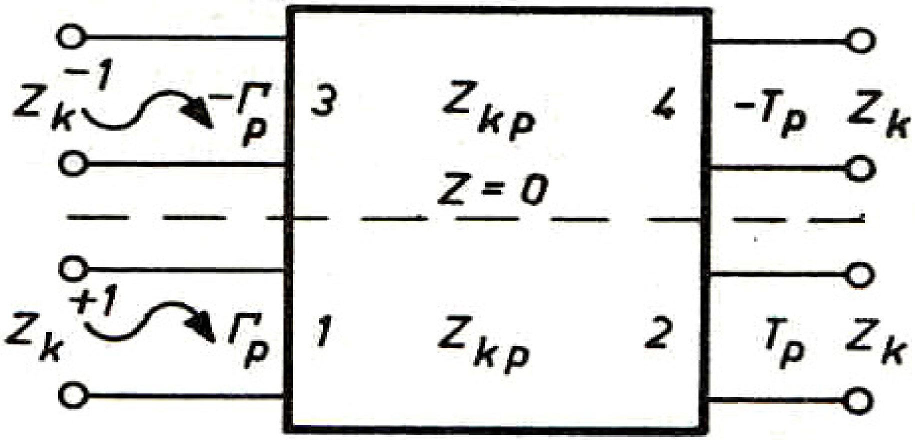
Sofazno in protifazno vzbujanje



(a)



Sofazno (sodo)

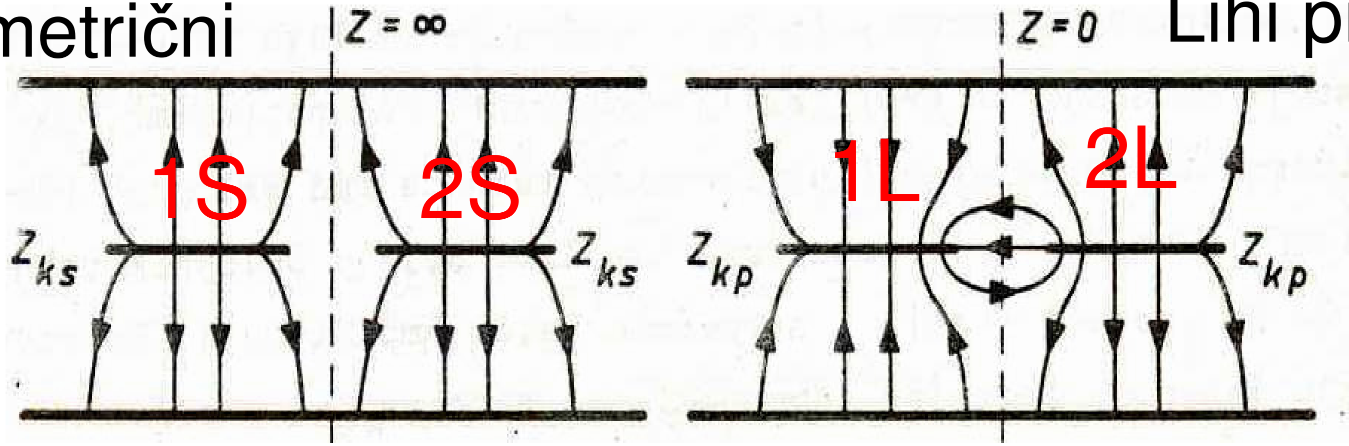


Protifazno (liho)

Sodi in lihi rodovi

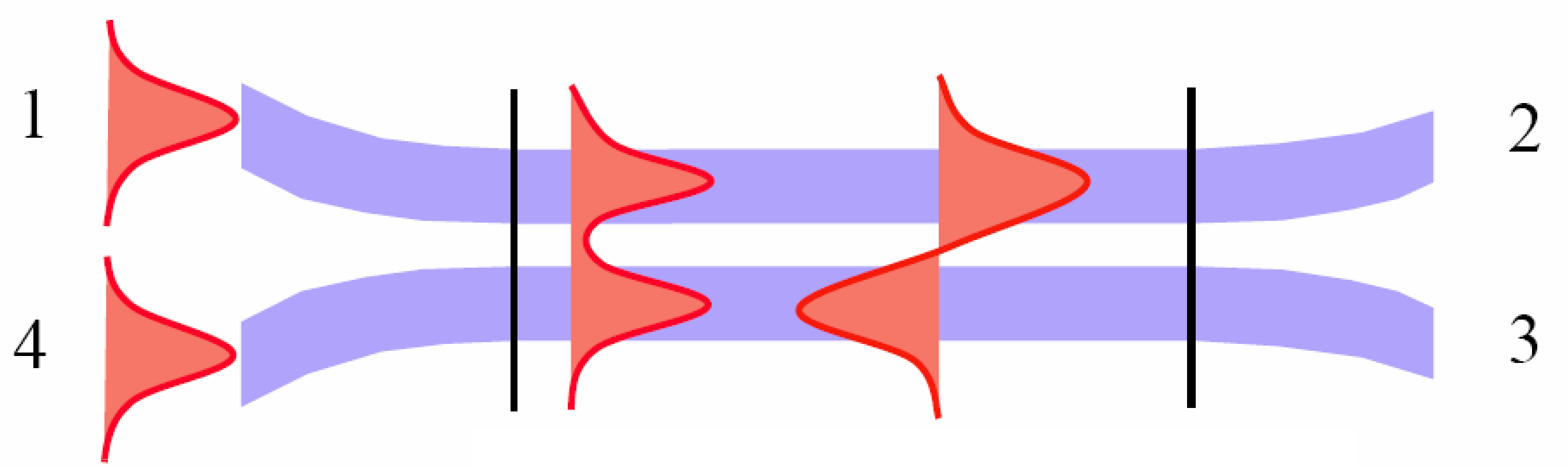
Sodi, simetrični

Lihi protisim.



$$I_1(z) = \underbrace{\frac{1}{Z_e}\left[A_e e^{-\frac{j\omega z}{v_e}} - B_e e^{+\frac{j\omega z}{v_e}}\right]}_{2S} + \underbrace{\frac{1}{Z_d}\left[A_d e^{-\frac{j\omega z}{v_d}} - B_d e^{+\frac{j\omega z}{v_d}}\right]}_{2L}$$

$$I_2(z) = \underbrace{\frac{1}{Z_e}\left[A_e e^{-\frac{j\omega z}{v_e}} - B_e e^{+\frac{j\omega z}{v_e}}\right]}_{2L} - \underbrace{\frac{1}{Z_d}\left[A_d e^{-\frac{j\omega z}{v_d}} - B_d e^{+\frac{j\omega z}{v_d}}\right]}_{1L}$$



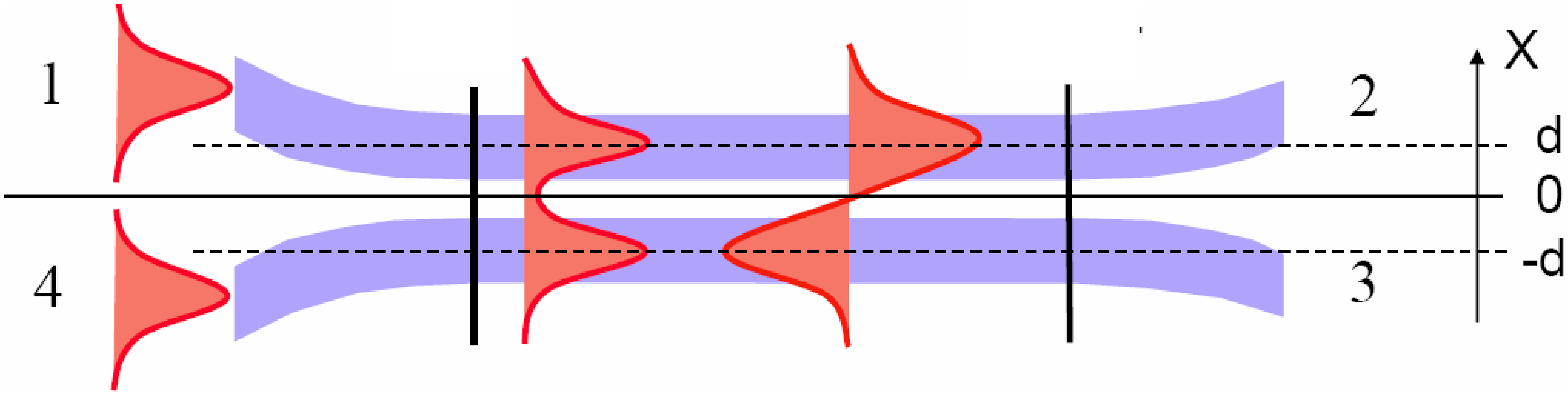
$$L_T = -10 \,Lg\, P_2/P_1$$

$$L_C = -10 \,Lg\, P_3/P_1$$

$$L_D = -10 \,Lg\, P_4/P_1$$

$$L_E = -10 \,Lg\, (P_3 + P_2)/P_1$$

Sodi in lihi rodovi



$$E_{in}(x) = E_{01} \cdot e^{-\frac{(x-d)^2}{w^2}}$$

$$A_{sm}(x-d) = e^{-\frac{(x-d)^2}{w^2}}$$

$$E_{in}(x) = E_{01} \cdot A_{sm}(x-d)$$

$$A_e(x) = A_{sm}(x-d) + A_{sm}(x+d)$$

$$A_o(x) = A_{sm}(x-d) - A_{sm}(x+d)$$

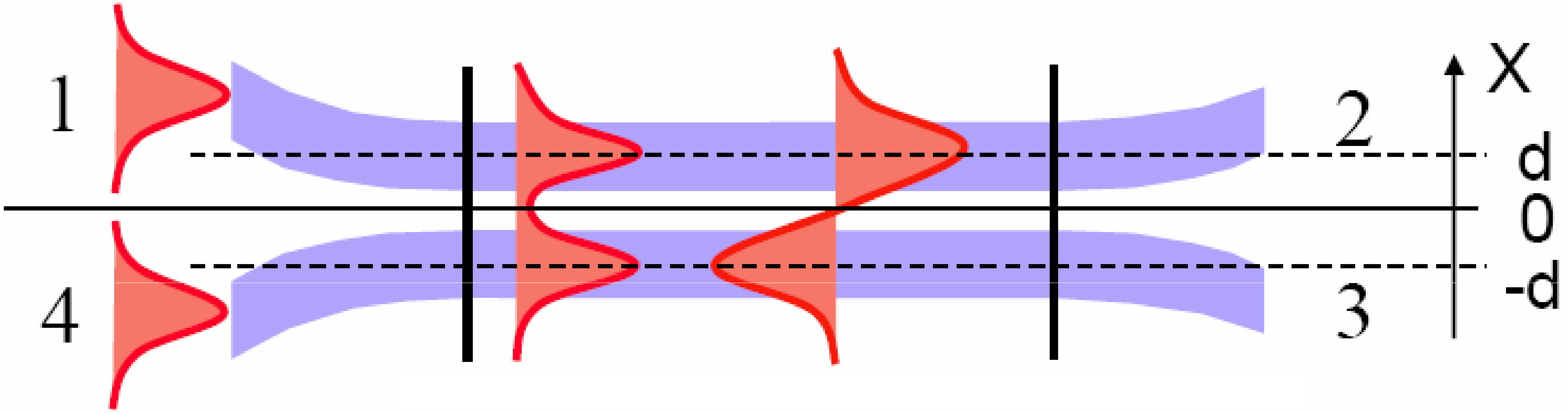
$$A_{sm}(x-d) = \frac{1}{2} \cdot (A_e + A_o)$$

$$A_{sm}(x+d) = \frac{1}{2} \cdot (A_e - A_o)$$

Sodi in lihi rodovi

$$E_{in} = E_{01} \cdot \frac{1}{2}\left(A_e + A_o\right)$$

$$E_{out} = E_{01} \cdot \frac{1}{2}\left(A_e + A_o \cdot e^{-\Delta\beta \cdot L}\right)$$

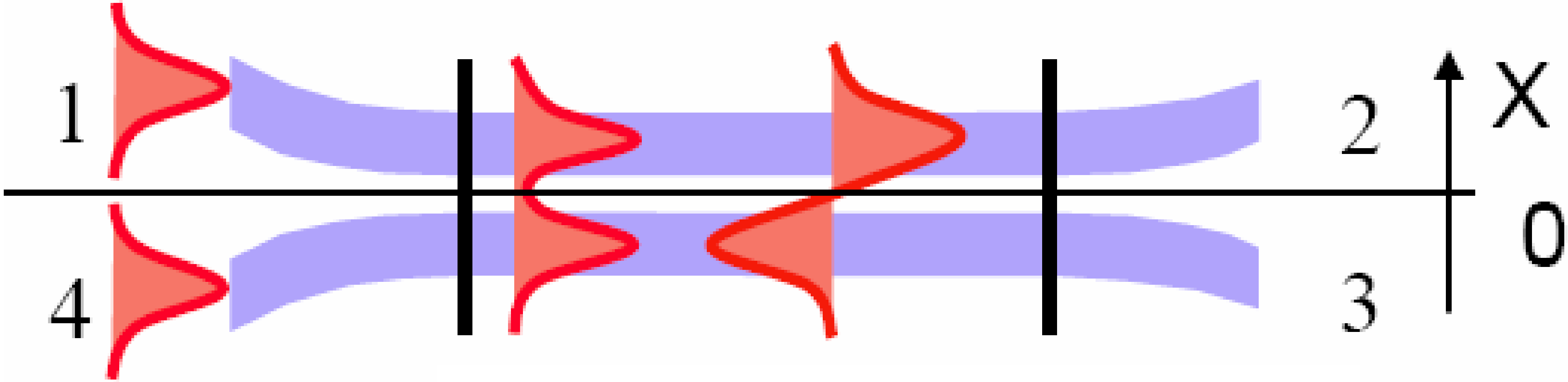


$$E_{out} = E_{01} \cdot \frac{1}{2}\left(A_{sm}(x-d) + A_{sm}(x+d) + A_{sm}(x-d) \cdot e^{-\Delta\beta \cdot L} - A_{sm}(x+d) \cdot e^{-\Delta\beta \cdot L}\right)$$

$$E_2 \approx E_{01} \cdot \frac{1}{2}(1 + e^{-\Delta\beta \cdot L}) A_{sm}(x-d)$$

$$E_3 \approx E_{01} \cdot \frac{1}{2}(1 - e^{-\Delta\beta \cdot L}) A_{sm}(x+d)$$

Prenos moči med vodnikoma



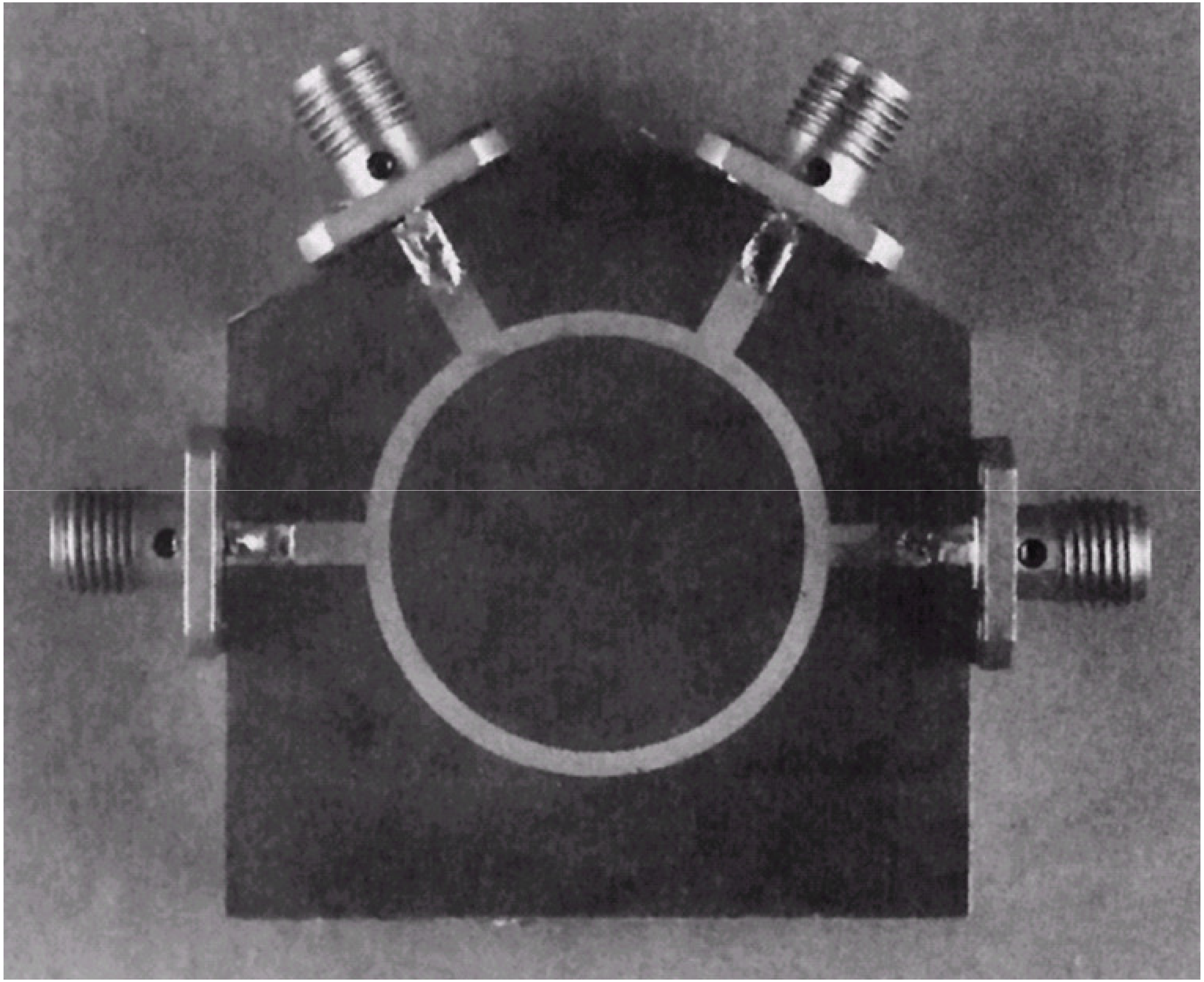
$$P_2 = 0.5 P_{in\,0} \left[|C_1|^2 + |C_2|^2 + 2|C_1||C_2|\cos(\Delta\beta L) \right]$$

$$P_3 = 0.5 P_{in\,0} \left[|C_1|^2 + |C_2|^2 - 2|C_1||C_2|\cos(\Delta\beta L) \right]$$

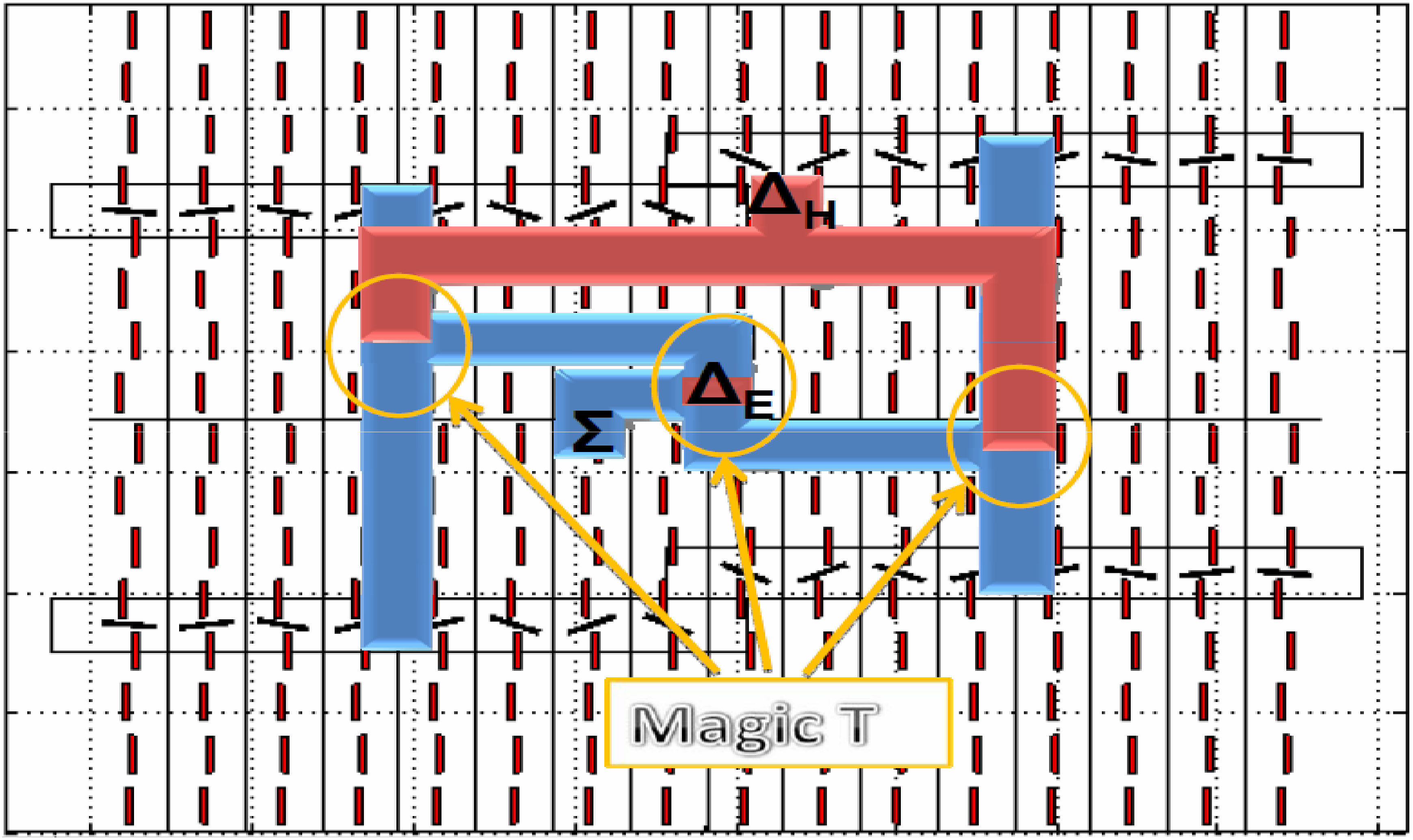
$$C_1 = C_2 = \sqrt{2} \Rightarrow$$

$$P_2 = 0.5 P_{in\,0} \left[1 + \cos(\Delta\beta L) \right]$$

$$P_3 = 0.5 P_{in\,0} \left[1 - \cos(\Delta\beta L) \right]$$



Radarska antena z Σ in Δ vzbujanjem



Z delilniki (magični T) vzbujana planarna skupina vzdolžnih rež v širši stranici vzporednih valovodov. Antena seva sumarni in diferenčni diagram hkrati. Zahtevna tehnika.

Sklep

Mikrovalovna vezja so pomemben sestavni del radijskih naprav

Štiripolna, šestpolna in osempolna vezja imajo primerno velikost pri frekvenci 900 MHz in navzgor

Integrirana vezja se izdelujejo v planarni tehniki, so cenena in primerna za izdelovanje v velikih količinah.

$$\left|S_{12}\right|^2+\left|S_{13}\right|^2=1\ ,\ \left|S_{12}\right|^2+\left|S_{24}\right|^2=1,\ \left|S_{13}\right|^2+\left|S_{34}\right|^2=1\ ,\ \left|S_{24}\right|^2+\left|S_{34}\right|^2=1$$

$$\left|S_{13}\right|=\left|S_{24}\right|=\beta\ ,\ \left|S_{12}\right|=\left|S_{34}\right|=\alpha$$

$$S_{12}=S_{34}=\alpha\ ,S_{13}=\beta e^{j\theta}\ ,S_{24}=\beta e^{j\phi}$$

$$S_{12}^*S_{13}+S_{24}^*S_{34}=0\Rightarrow\theta+\phi=\pi\pm 2n\pi$$

$$\alpha^2+\beta^2=1\ ,\ n=0$$

$$[S]=\begin{bmatrix}0 & \alpha & j\beta & 0\\ \alpha & 0 & 0 & j\beta\\ j\beta & 0 & 0 & \alpha\\ 0 & j\beta & \alpha & 0\end{bmatrix}\quad \theta=\phi=\frac{\pi}{2}$$

$$[S]=\begin{bmatrix}0 & \alpha & \beta & 0\\ \alpha & 0 & 0 & \beta\\ \beta & 0 & 0 & \alpha\\ 0 & \beta & \alpha & 0\end{bmatrix}\quad \theta=0,\ \phi=\pi$$

8-polno prilagojeno, recipročno, brez izgub

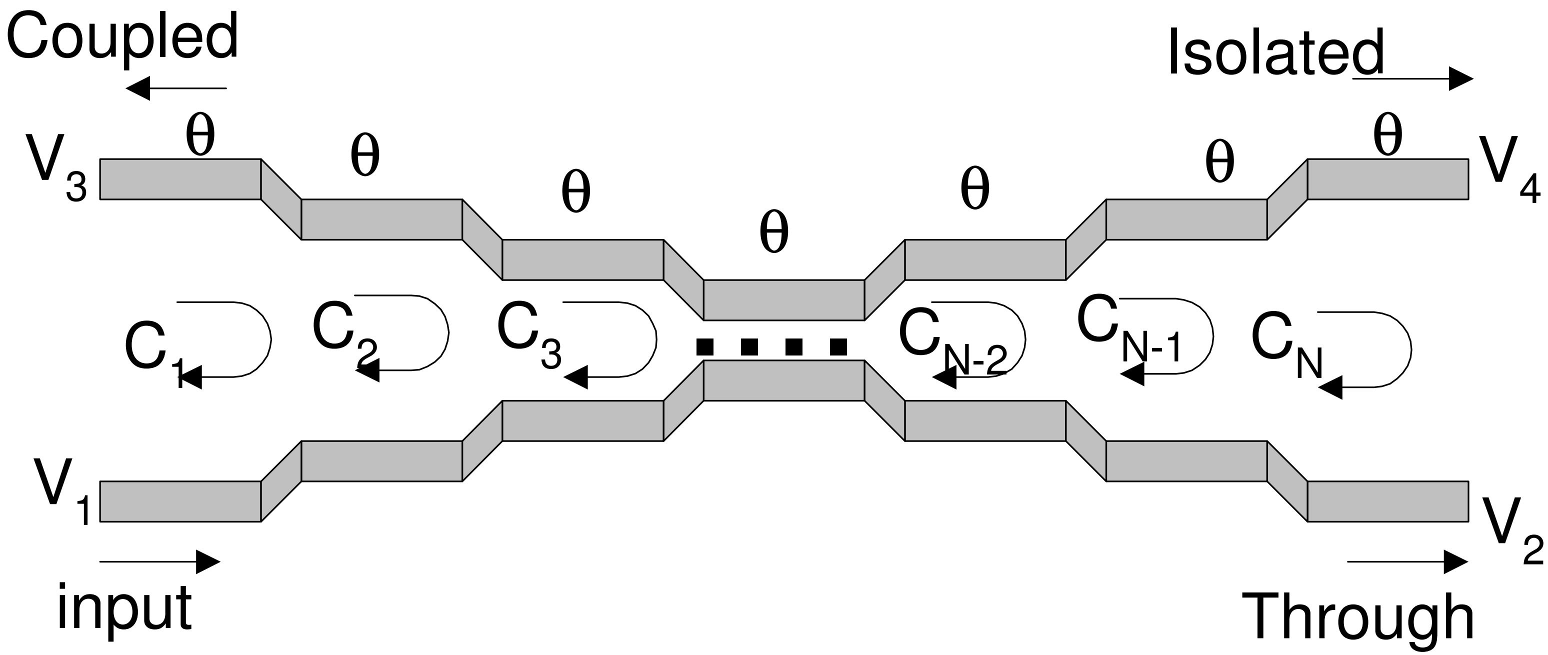
$$\begin{bmatrix} 0 & S_{12} & S_{13} & S_{14} \\ S_{12} & 0 & S_{23} & S_{24} \\ S_{13} & S_{23} & 0 & S_{34} \\ S_{14} & S_{24} & S_{34} & 0 \end{bmatrix} \rightarrow \begin{array}{l} \text{row } 1^*, 2: S_{13}^* S_{23} + S_{14}^* S_{24} = 0 \ldots (1) \\ \text{row } 3, 4^*: S_{14}^* S_{13} + S_{24}^* S_{23} = 0 \ldots (2) \\ \text{row } 1^*, 3: S_{12}^* S_{23} + S_{14}^* S_{34} = 0 \ldots (3) \\ \text{row } 2, 4^*: S_{14}^* S_{12} + S_{34}^* S_{23} = 0 \ldots (4) \end{array} \begin{array}{l} \xrightarrow{(1)S_{24}^* - (2)S_{13}^*} S_{14}^* \left(|S_{13}|^2 - |S_{24}|^2 \right) = 0 \\ \xrightarrow{(3)S_{12} - (4)S_{34}} S_{23} \left(|S_{12}|^2 - |S_{34}|^2 \right) = 0 \end{array}$$

$$S_{14} = S_{23} = 0 \rightarrow \begin{bmatrix} 0 & S_{12} & S_{13} & 0 \\ S_{12} & 0 & 0 & S_{24} \\ S_{13} & 0 & 0 & S_{34} \\ 0 & S_{24} & S_{34} & 0 \end{bmatrix} \rightarrow \begin{array}{l} |S_{12}|^2 + |S_{13}|^2 = 1 \\ |S_{12}|^2 + |S_{24}|^2 = 1 \\ |S_{13}|^2 + |S_{34}|^2 = 1 \\ |S_{24}|^2 + |S_{34}|^2 = 1 \end{array} \rightarrow \begin{array}{l} |S_{13}| = |S_{24}| \\ |S_{12}| = |S_{34}| \end{array} \rightarrow \begin{array}{l} S_{12} = S_{34} = \alpha \\ S_{13} = \beta e^{j\theta} \\ S_{24} = \beta e^{j\phi} \\ \alpha^2 + \beta^2 = 1 \end{array}$$

$$S_{12}^* S_{13} + S_{24}^* S_{34} = 0 \rightarrow e^{j\theta} + e^{-j\phi} = 0 \rightarrow \theta + \phi = \pi$$

$$\begin{bmatrix} 0 & \alpha & j\beta & 0 \\ \alpha & 0 & 0 & j\beta \\ j\beta & 0 & 0 & \alpha \\ 0 & j\beta & \alpha & 0 \end{bmatrix} \qquad \begin{bmatrix} 0 & \alpha & \beta & 0 \\ \alpha & 0 & 0 & -\beta \\ \beta & 0 & 0 & \alpha \\ 0 & -\beta & \alpha & 0 \end{bmatrix}$$

Multisection Coupled line coupler (broadband)



For single section , whence C<<1 , then

$$\frac{V_3}{V_1} = \frac{jC\tan\theta}{\sqrt{1-C^2} + j\tan\theta} \approx \frac{jC\tan\theta}{1+j\tan\theta} = jC\sin\theta\, e^{-j\theta}$$

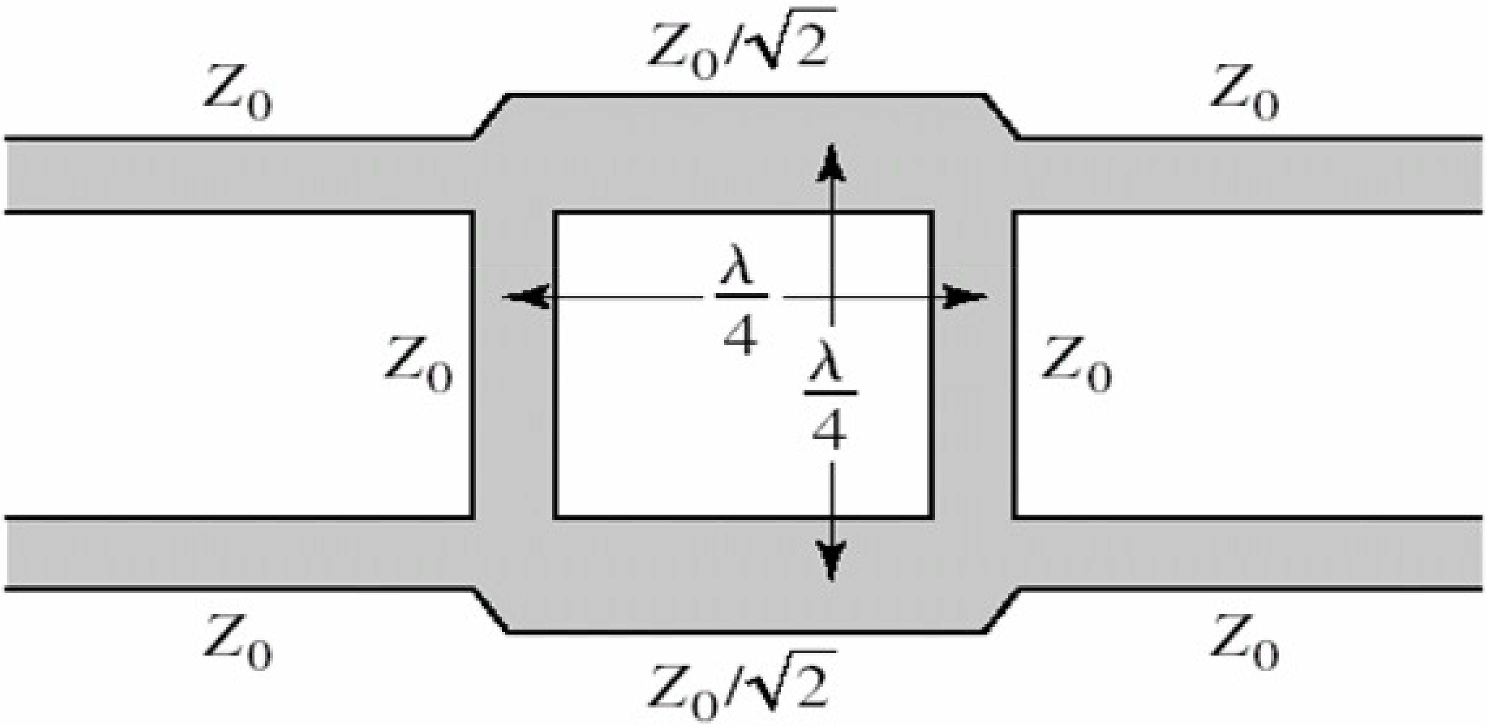
$V_4=0$

$$\frac{V_2}{V_1} = \frac{\sqrt{1-C^2}}{\sqrt{1-C^2}\cos\theta + j\sin\theta} \approx e^{-j\vartheta}$$

and

For $\theta = \pi / 2$ then $V_3/V_1 = C$ and $V_2/V_1 = -j$

Trakasti kvadratni hibrid



Directional coupler

If all ports matched , symmetry and $S_{14}=S_{23}=0$ to be satisfied

$$[S]=\begin{bmatrix} 0 & S_{12} & S_{13} & 0 \\ S_{12} & 0 & 0 & S_{24} \\ S_{13} & 0 & 0 & S_{34} \\ 0 & S_{24} & S_{34} & 0 \end{bmatrix}$$

The equations reduce to 6 equations

$$** \ |S_{12}|+|S_{13}|=1$$

$$* \ |S_{12}|+|S_{24}|=1$$

$$** \ |S_{13}|+|S_{34}|=1$$

$$* \ |S_{24}|+|S_{34}|=1$$

$$S_{12}S_{24}^{*}+S_{13}S_{34}^{*}=0$$

$$S_{12}S_{13}^{*}+S_{24}S_{34}^{*}=0$$

By comparing these equations yield $|S_{13}|=|S_{24}|$

By comparing equations * and ** yield $|S_{12}|=|S_{34}|$