$u=R\cdot i$ $\quad i=G\cdot u$ $\quad R=\frac{u}{i}$ $\quad G=\frac{i}{u}$ $\quad \underbrace{p=R\cdot i^2}_{\geq 0}$ $\quad \underbrace{p=G\cdot u^2}_{\leq 0}$

$u', i' = Q$
$u, i = L$

$u=0=KS$ $\quad i=0=LL$

Konk.-& konv. Wid.

$Q.$ frei $=(0,0)$

Dualwandlung

$i^d=\frac{u}{Rd}$ $\quad u^d=i\cdot Rd$

LL $\quad$ KS

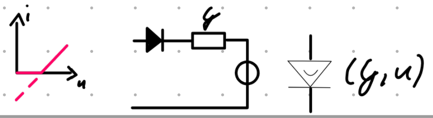
Schalter $\begin{cases}1, \text{zu}, KS\\ 0, \text{offen}, LL\end{cases}$

Umpolung

$g_{\bar{F}}(\bar{u})=-g_F(-\bar{u})$

$v_{\bar{F}}(\bar{i})=-v_F(-\bar{i})$

Konk.



Diode

$u<0,\ i=0$

$u=0,\ i>0$

Parallel

$i_1+i_2 \quad u_1=u_2$

$R_1 \| R_2 \quad G_1+G_2$

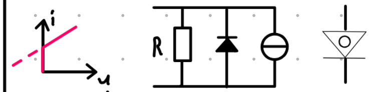
Serie

$i_1=i_2 \quad u_1+u_2$

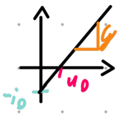
$R_1+R_2 \quad G_1 \| G_2$

$a \| b=\frac{a\cdot b}{a+b}$

Konv.



Lin Quellen



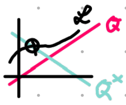
$y=m\cdot x$

$i'=G\cdot(u'-u_0)=G\cdot u'-i_0$

$i=\sum$ Str. $=$ Par. Str. Q

$u=\sum$ Sp. $=$ Ser. Sp. Q

$Q^*=Q(u,-i)$



AP finden

Fehlt: • Großsig. Ana.
• Kleinsignalanalyse
• Lin impl. Beschr.

Lin.

$\beta(a)\approx\beta(A)+K\cdot(a-A)$

$u_{lin}\approx\frac{dv_F(i)}{di}\Big|_{i=I}\cdot(i-I)+v_F(I)$

$(sin(x)'=cos(x)\ |\ cos(x)'=-sin(x)$

$(f(x)*g(x))'=f(x)'*g(x)+g(x)'*f(x)$

$(f(x)\pm g(x))'=f(x)'\pm g(x)'\ |\ (c*f(x))'=c*f(x)'$

$\left(\frac{f(x)}{g(x)}\right)'=\frac{f(x)'*g(x)-f(x)*g(x)'}{g(x)^2}$

$(e^x)'=e^x$

$x'=1$

$k^x=\ln(k)\cdot k^x$

$k'=0$

$(x^n)'=n\cdot x^{n-1}$

$\ln(x)'=\frac{1}{x}$

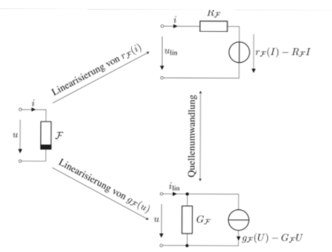


Abbildung 3.33: Linearisierung eines nichtlinearen Eintors $\mathcal{F}$

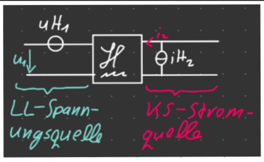
Matrix $A=\begin{pmatrix}a&b\\c&d\end{pmatrix}$ $\quad \det(A)=a\cdot d-b\cdot c$ $\quad A=\begin{bmatrix}a_{11}&a_{12}\\a_{21}&a_{22}\end{bmatrix}\rightarrow a_{\text{Zeile Spalte}}$ $\quad \frac{1}{x}\rightarrow$ Matrix existiert if $x\neq 0$

Gegeben $\rightarrow$

gesucht $\downarrow$

	R	G	H	H'	A	A'
R	$\begin{bmatrix}r_{11}&r_{12}\\r_{21}&r_{22}\end{bmatrix}$	$\frac{1}{\det G}\begin{bmatrix}g_{22}&-g_{12}\\-g_{21}&g_{11}\end{bmatrix}$	$\frac{1}{h_{22}}\begin{bmatrix}\det H&h_{12}\\-h_{21}&1\end{bmatrix}$	$\frac{1}{h'_{11}}\begin{bmatrix}1&-h'_{12}\\h'_{21}&\det H'\end{bmatrix}$	$\frac{1}{a_{21}}\begin{bmatrix}a_{11}&\det A\\1&a_{22}\end{bmatrix}$	$\frac{1}{a'_{21}}\begin{bmatrix}a'_{22}&1\\\det A'&a'_{11}\end{bmatrix}$
G	$\frac{1}{\det R}\begin{bmatrix}r_{22}&-r_{12}\\-r_{21}&r_{11}\end{bmatrix}$	$\begin{bmatrix}g_{11}&g_{12}\\g_{21}&g_{22}\end{bmatrix}$	$\frac{1}{h_{11}}\begin{bmatrix}1&-h_{12}\\h_{21}&\det H\end{bmatrix}$	$\frac{1}{h'_{22}}\begin{bmatrix}\det H'&h'_{12}\\-h'_{21}&1\end{bmatrix}$	$\frac{1}{a_{12}}\begin{bmatrix}a_{22}&-\det A\\-1&a_{11}\end{bmatrix}$	$\frac{1}{a'_{12}}\begin{bmatrix}a'_{11}&-1\\-\det A'&a'_{22}\end{bmatrix}$
H	$\frac{1}{r_{22}}\begin{bmatrix}\det R&r_{12}\\-r_{21}&1\end{bmatrix}$	$\frac{1}{g_{11}}\begin{bmatrix}1&-g_{12}\\g_{21}&\det G\end{bmatrix}$	$\begin{bmatrix}h_{11}&h_{12}\\h_{21}&h_{22}\end{bmatrix}$	$\frac{1}{\det H'}\begin{bmatrix}h'_{22}&-h'_{12}\\-h'_{21}&h'_{11}\end{bmatrix}$	$\frac{1}{a_{22}}\begin{bmatrix}a_{12}&\det A\\-1&a_{21}\end{bmatrix}$	$\frac{1}{a'_{11}}\begin{bmatrix}a'_{12}&1\\-\det A'&a'_{21}\end{bmatrix}$
H'	$\frac{1}{r_{11}}\begin{bmatrix}1&-r_{12}\\r_{21}&\det R\end{bmatrix}$	$\frac{1}{g_{22}}\begin{bmatrix}\det G&g_{12}\\-g_{21}&1\end{bmatrix}$	$\frac{1}{\det H}\begin{bmatrix}h_{22}&-h_{12}\\-h_{21}&h_{11}\end{bmatrix}$	$\begin{bmatrix}h'_{11}&h'_{12}\\h'_{21}&h'_{22}\end{bmatrix}$	$\frac{1}{a_{11}}\begin{bmatrix}a_{21}&-\det A\\1&a_{12}\end{bmatrix}$	$\frac{1}{a'_{22}}\begin{bmatrix}a'_{21}&-1\\\det A'&a'_{12}\end{bmatrix}$
A	$\frac{1}{r_{21}}\begin{bmatrix}r_{11}&\det R\\1&r_{22}\end{bmatrix}$	$\frac{1}{g_{21}}\begin{bmatrix}-g_{22}&-1\\-\det G&-g_{11}\end{bmatrix}$	$\frac{1}{h_{21}}\begin{bmatrix}-\det H&-h_{11}\\-h_{22}&-1\end{bmatrix}$	$\frac{1}{h'_{21}}\begin{bmatrix}1&h'_{22}\\h'_{11}&\det H'\end{bmatrix}$	$\begin{bmatrix}a_{11}&a_{12}\\a_{21}&a_{22}\end{bmatrix}$	$\frac{1}{\det A'}\begin{bmatrix}a'_{22}&a'_{12}\\a'_{21}&a'_{11}\end{bmatrix}$
A'	$\frac{1}{r_{12}}\begin{bmatrix}r_{22}&\det R\\1&r_{11}\end{bmatrix}$	$\frac{1}{g_{12}}\begin{bmatrix}-g_{11}&-1\\-\det G&-g_{22}\end{bmatrix}$	$\frac{1}{h_{12}}\begin{bmatrix}1&h_{11}\\h_{22}&\det H\end{bmatrix}$	$\frac{1}{h'_{12}}\begin{bmatrix}-\det H'&-h'_{22}\\-h'_{11}&-1\end{bmatrix}$	$\frac{1}{\det A}\begin{bmatrix}a_{22}&a_{12}\\a_{21}&a_{11}\end{bmatrix}$	$\begin{bmatrix}a'_{11}&a'_{12}\\a'_{21}&a'_{22}\end{bmatrix}$

2-Tore



str. lin. & Q-frei
• 4 lin. un. Messungen
• Kernbeschr. gibt es immer
• Bildbeschr. ($\rightarrow$ 2 Mess.)

$$\begin{bmatrix}i_1\\i_2\end{bmatrix}=G\begin{bmatrix}u_1\\u_2\end{bmatrix}=\begin{bmatrix}g_{11}u_1+g_{12}u_2\\g_{21}u_1+g_{22}u_2\end{bmatrix} \qquad \begin{bmatrix}i_1\\i_2\end{bmatrix}=G\begin{bmatrix}u_1\\u_2\end{bmatrix}+\begin{bmatrix}i_{G1}\\i_{G2}\end{bmatrix}$$

$$\begin{bmatrix}u_1\\u_2\end{bmatrix}=R\begin{bmatrix}i_1\\i_2\end{bmatrix}=\begin{bmatrix}r_{11}i_1+r_{12}i_2\\r_{21}i_1+r_{22}i_2\end{bmatrix} \qquad \begin{bmatrix}u_1\\u_2\end{bmatrix}=R\begin{bmatrix}i_1\\i_2\end{bmatrix}+\begin{bmatrix}u_{R1}\\u_{R2}\end{bmatrix}$$

$$\begin{bmatrix}u_1\\i_2\end{bmatrix}=H\begin{bmatrix}i_1\\u_2\end{bmatrix}=\begin{bmatrix}h_{11}i_1+h_{12}u_2\\h_{21}i_1+h_{22}u_2\end{bmatrix} \qquad \begin{bmatrix}u_1\\i_2\end{bmatrix}=H\begin{bmatrix}i_1\\u_2\end{bmatrix}+\begin{bmatrix}u_{H1}\\i_{H2}\end{bmatrix}$$

$$\begin{bmatrix}i_1\\u_2\end{bmatrix}=H'\begin{bmatrix}u_1\\i_2\end{bmatrix}=\begin{bmatrix}h'_{11}u_1+h'_{12}i_2\\h'_{21}u_1+h'_{22}i_2\end{bmatrix} \qquad \begin{bmatrix}i_1\\u_2\end{bmatrix}=H'\begin{bmatrix}u_1\\i_2\end{bmatrix}+\begin{bmatrix}i_{H'1}\\u_{H'2}\end{bmatrix}$$

$$\begin{bmatrix}u_1\\i_1\end{bmatrix}=A\begin{bmatrix}u_2\\-i_2\end{bmatrix}=\begin{bmatrix}a_{11}u_2-a_{12}i_2\\a_{21}u_2-a_{22}i_2\end{bmatrix} \qquad \begin{bmatrix}u_1\\i_1\end{bmatrix}=A\begin{bmatrix}u_2\\-i_2\end{bmatrix}+\begin{bmatrix}u_{A1}\\i_{A1}\end{bmatrix}$$

$$\begin{bmatrix}u_2\\i_2\end{bmatrix}=A'\begin{bmatrix}u_1\\-i_1\end{bmatrix}=\begin{bmatrix}a'_{11}u_1-a'_{12}i_1\\a'_{21}u_1-a'_{22}i_1\end{bmatrix} \qquad \begin{bmatrix}u_2\\i_2\end{bmatrix}=A'\begin{bmatrix}u_1\\-i_1\end{bmatrix}+\begin{bmatrix}u_{A'2}\\i_{A'2}\end{bmatrix}$$

$g_{11}=\frac{i_1}{u_1}\Big\vert_{u_2=0}$	$\underbrace{\text{Eingangsleitwert}}_{1.\ \text{Tor}}$ bei kurzgeschlossenem Ausgang (2. Tor)	$r_{11}=\frac{u_1}{i_1}\Big\vert_{i_2=0}$	Eingangswiderstand bei leerlaufendem Ausgang
$g_{22}=\frac{i_2}{u_2}\Big\vert_{u_1=0}$	Ausgangsleitwert bei kurzgeschlossenem Eingang	$r_{22}=\frac{u_2}{i_2}\Big\vert_{i_1=0}$	Ausgangswiderstand bei leerlaufendem Eingang
$g_{21}=\frac{i_2}{u_1}\Big\vert_{u_2=0}$	Vorwärtstransferleitwert bei kurzgeschl. Ausgang	$r_{21}=\frac{u_2}{i_1}\Big\vert_{i_2=0}$	Vorwärtstransferwiderstand bei leerlaufendem Ausgang
$g_{12}=\frac{i_1}{u_2}\Big\vert_{u_1=0}$	Rückwärtstransferleitwert bei kurzgeschl. Eingang	$r_{12}=\frac{u_1}{i_2}\Big\vert_{i_1=0}$	Rückwärtstransferwiderstand bei leerlaufendem Eingang

Transfer $\rightarrow$ wie sich ein Tor auf das andere auswirkt

Rise
Run

nicht Q-freies lin. 2-Tor

• str. lin. 2-Tor + lin. Q.

$F=[\underset{\sim}{M},\underset{\sim}{N}]\cdot\begin{bmatrix}\underline{u}-\underline{u_0}\\\underline{i}-\underline{i_0}\end{bmatrix}$ $\quad$ 3 Messungen

$\begin{bmatrix}\underline{u}\\\underline{i}\end{bmatrix}=\begin{bmatrix}\underset{\sim}{u}\\\underset{\sim}{i}\end{bmatrix}\cdot c+\begin{bmatrix}\underline{u_0}\\\underline{i_0}\end{bmatrix}$

VCCS $\quad G=\begin{bmatrix}0&0\\g&0\end{bmatrix}$ $\quad A=\begin{bmatrix}0&-\frac{1}{g}\\0&0\end{bmatrix}$

CCCS $\quad H=\begin{bmatrix}0&0\\\beta&0\end{bmatrix}$ $\quad A=\begin{bmatrix}0&0\\0&-\frac{1}{\beta}\end{bmatrix}$

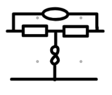
VCVS $\quad H=\begin{bmatrix}0&0\\\mu&0\end{bmatrix}$ $\quad A=\begin{bmatrix}\frac{1}{\mu}&0\\0&0\end{bmatrix}$

CCVS $\quad R=\begin{bmatrix}0&0\\r&0\end{bmatrix}$ $\quad A=\begin{bmatrix}0&0\\\frac{1}{r}&0\end{bmatrix}$

NIK

$R_1=-R_2$

$A=\begin{bmatrix}-k&0\\0&\frac{1}{k}\end{bmatrix}$



Lin. 2-Tore

$$\underset{\sim}{J}=\begin{bmatrix}\frac{\delta h_1(i_1,u_2)}{\delta i_1}&\frac{\delta h_1(i_1,u_2)}{\delta u_2}\\\frac{\delta h_2(i_1,u_2)}{\delta i_1}&\frac{\delta h_2(i_1,u_2)}{\delta u_2}\end{bmatrix}$$

Verlustlos

$\underset{\sim}{U}^T\cdot\underset{\sim}{I}+\underset{\sim}{I}^T\cdot\underset{\sim}{U}=0$

Symmetrie

$\underset{\sim}{P}=\begin{bmatrix}0&1\\1&0\end{bmatrix}$

Symm. if

$\underset{\sim}{M}=\underset{\sim}{P}\cdot\underset{\sim}{M}\cdot\underset{\sim}{P}$

Rez.

$R\,\&\,G\Rightarrow b=c$

$H\Rightarrow b=-c$

$A\Rightarrow Det=1$

$\underset{\sim}{u}^T\cdot\underset{\sim}{I}-\underset{\sim}{I}^T\underset{\sim}{u}=0$

Nullor $\quad$ = gesd. Q.

$1:\ddot{u}$

Übertrager $\quad$ Rez. & Verlustlos

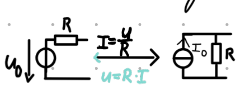
$\underset{\sim}{U}^T\cdot\underset{\sim}{I}=0$ $\quad H=\begin{bmatrix}0&\ddot{u}\\-\ddot{u}&0\end{bmatrix}$ $\quad A=\begin{bmatrix}\ddot{u}&0\\0&-\frac{1}{\ddot{u}}\end{bmatrix}$

Gyrator $\quad$ nicht Rez. & verlustlos

$\underset{\sim}{R}=-\underset{\sim}{R}^T$ $\quad R=\begin{bmatrix}0&-Rd\\Rd&0\end{bmatrix}$ $\quad A=\begin{bmatrix}0&+Rd\\\frac{1}{Rd}&0\end{bmatrix}$

• $Tor_1=Tor_2^d$

Quellenwandlung



$i_{1lin}=\frac{\partial g_1(u_1,u_2)}{\partial u_1}\Big|_{\underline{u}=\underline{U}}(u_1-U_1)+\frac{\partial g_1(u_1,u_2)}{\partial u_2}\Big|_{\underline{u}=\underline{U}}(u_2-U_2)+I_1$ $\quad$ (Δi_1)

$i_{2lin}=\frac{\partial g_2(u_1,u_2)}{\partial u_1}\Big|_{\underline{u}=\underline{U}}(u_1-U_1)+\frac{\partial g_2(u_1,u_2)}{\partial u_2}\Big|_{\underline{u}=\underline{U}}(u_2-U_2)+I_2$ $\quad$ (Δi_2)

$$\underset{\sim}{G}=\begin{bmatrix}\frac{\partial g_1(\underline{u})}{\partial u_1}&\frac{\partial g_1(\underline{u})}{u_2}\\\frac{\partial g_2(\underline{u})}{u_1}&\frac{\partial g_2(\underline{u})}{u_2}\end{bmatrix}\Bigg|_{\underline{u}=\underline{U}}$$

2-Tor lin
$\downarrow$
Lin. nicht Q-frei 2-Tor

Sp. Teiler

serie

$u_1=\frac{R_1}{R_g}\cdot u_g$

$u_1=\frac{G_2}{G_1+G_2}\cdot u_g$

Str. Teiler

Para.

$i_1=\frac{G_1}{G_g}\cdot i_g$

Dualwandlung 2-Tor

$\underset{\sim}{G}^d=\frac{1}{R_d^2}\cdot\underset{\sim}{R}$ $\qquad \underset{\sim}{R}^d=R_d^2\cdot\underset{\sim}{G}$

*	1	2	3	4	5	6	7	8	9	10
1	1	2	3	4	5	6	7	8	9	10
2	2	4	6	8	10	12	14	16	18	20
3	3	6	9	12	15	18	21	24	27	30
4	4	8	12	16	20	24	28	32	36	40
5	5	10	15	20	25	30	35	40	45	50
6	6	12	18	24	30	36	42	48	54	60
7	7	14	21	28	35	42	49	56	63	70
8	8	16	24	32	40	48	56	64	72	80
9	9	18	27	36	45	54	63	72	81	90
10	10	20	30	40	50	60	70	80	90	100