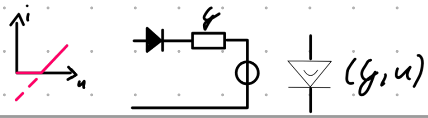
$u=R\cdot i$ $i=g\cdot u$ $R=\frac{u}{i}$ $g=\frac{i}{u}$ $p=R\cdot i^2 \geq 0$ $p=g\cdot u^2 \leq 0$ R

$u', i' = \mathcal{Q}$ $u, i = \mathcal{L}$ $\ominus u=0=KS$ $\ominus i=0=LL$

Konk.- & konv. wid.

Konk.



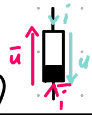
$\mathcal{Q}$. frei $=(0,0)$

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

Umpolung

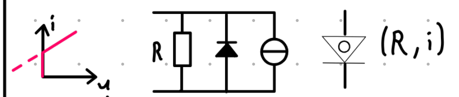
$g_{\mathcal{F}}(\bar{u}) = -g_{\mathcal{F}}(-\bar{u})$

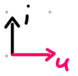
$v_{\mathcal{F}}(\bar{i}) = -v_{\mathcal{F}}(-\bar{i})$



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

Konv.



LL  KS 

Diode

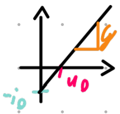
$u<0, i=0$

$u=0, i>0$

Parallel	Serie
i_1+i_2 $u_1=u_2$	$i_1=i_2$ u_1+u_2
$R_1 \parallel R_2$ g_1+g_2	R_1+R_2 $g_1 \parallel g_2$

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

Lin Quellen



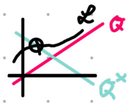
$y = m \cdot x$

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

$i = \sum$ Str. = Par. Str. $\mathcal{Q}$

$u = \sum$ Sp. = Ser. Sp. $\mathcal{Q}$

$\mathcal{Q}^* = \mathcal{Q}(u,-i)$



Fehlt: · Großsig. Ana.

· Kleinsignalanalyse

· Lin impl. Beschr.

Lin.

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

$u_{lin} \approx \frac{d v_{\mathcal{F}}(i)}{di}\Big|_{i=I}\cdot(i-I)+v_{\mathcal{F}}(I)$

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

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

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

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

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

$x' = 1$

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

$k' = 0$

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

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

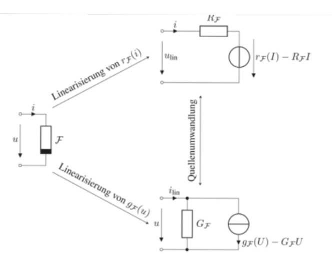


Abbildung 3.33: Linearisierung eines nichtlinearen Eintors $\mathcal{F}$

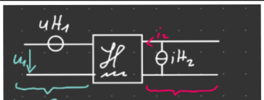
Matrix $A=\begin{pmatrix}a & b\\ c & d\end{pmatrix}$ det(A) = a·d − b·c $A=\begin{bmatrix}a_{11} & a_{12}\\ a_{21} & a_{22}\end{bmatrix} \rightarrow a_{\text{zeile spalte}}$ $\frac{1}{x} \rightarrow$ Matrix existiert if $x \neq 0$

Gegeben →

gesucht ↓

	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

· $\not\exists$ lin. un. Messungen

· Kernbeschr. gibt es immer

· Bildbeschr. (→ 2 Mess.)

$$\begin{bmatrix}i_1\\ i_2\end{bmatrix} = \boldsymbol{G}\begin{bmatrix}u_1\\ u_2\end{bmatrix} = \begin{bmatrix}g_{11}u_1+g_{12}u_2\\ g_{21}u_1+g_{22}u_2\end{bmatrix}$$

$$\begin{bmatrix}u_1\\ u_2\end{bmatrix} = \boldsymbol{R}\begin{bmatrix}i_1\\ i_2\end{bmatrix} = \begin{bmatrix}r_{11}i_1+r_{12}i_2\\ r_{21}i_1+r_{22}i_2\end{bmatrix}$$

$$\begin{bmatrix}u_1\\ i_2\end{bmatrix} = \boldsymbol{H}\begin{bmatrix}i_1\\ u_2\end{bmatrix} = \begin{bmatrix}h_{11}i_1+h_{12}u_2\\ h_{21}i_1+h_{22}u_2\end{bmatrix}$$

$$\begin{bmatrix}i_1\\ u_2\end{bmatrix} = \boldsymbol{H'}\begin{bmatrix}u_1\\ i_2\end{bmatrix} = \begin{bmatrix}h'_{11}u_1+h'_{12}i_2\\ h'_{21}u_1+h'_{22}i_2\end{bmatrix}$$

$$\begin{bmatrix}u_1\\ i_1\end{bmatrix} = \boldsymbol{A}\begin{bmatrix}u_2\\ -i_2\end{bmatrix} = \begin{bmatrix}a_{11}u_2-a_{12}i_2\\ a_{21}u_2-a_{22}i_2\end{bmatrix}$$

$$\begin{bmatrix}u_2\\ i_2\end{bmatrix} = \boldsymbol{A'}\begin{bmatrix}u_1\\ -i_1\end{bmatrix} = \begin{bmatrix}a'_{11}u_1-a'_{12}i_1\\ a'_{21}u_1-a'_{22}i_1\end{bmatrix}$$

$$\begin{bmatrix}i_1\\ i_2\end{bmatrix} = \boldsymbol{G}\begin{bmatrix}u_1\\ u_2\end{bmatrix} + \begin{bmatrix}i_{G1}\\ i_{G2}\end{bmatrix}$$

$$\begin{bmatrix}u_1\\ u_2\end{bmatrix} = \boldsymbol{R}\begin{bmatrix}i_1\\ i_2\end{bmatrix} + \begin{bmatrix}u_{R1}\\ u_{R2}\end{bmatrix}$$

$$\begin{bmatrix}u_1\\ i_2\end{bmatrix} = \boldsymbol{H}\begin{bmatrix}i_1\\ u_2\end{bmatrix} + \begin{bmatrix}u_{H1}\\ i_{H2}\end{bmatrix}$$

$$\begin{bmatrix}i_1\\ u_2\end{bmatrix} = \boldsymbol{H'}\begin{bmatrix}u_1\\ i_2\end{bmatrix} + \begin{bmatrix}i_{H'1}\\ u_{H'2}\end{bmatrix}$$

$$\begin{bmatrix}u_1\\ i_1\end{bmatrix} = \boldsymbol{A}\begin{bmatrix}u_2\\ -i_2\end{bmatrix} + \begin{bmatrix}u_{A1}\\ i_{A1}\end{bmatrix}$$

$$\begin{bmatrix}u_2\\ i_2\end{bmatrix} = \boldsymbol{A'}\begin{bmatrix}u_1\\ -i_1\end{bmatrix} + \begin{bmatrix}u_{A'2}\\ i_{A'2}\end{bmatrix}$$

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

Transfer → wie sich ein Tor auf das andere auswirkt

nicht Q-freies lin. 2-Tor

· str. lin. 2-Tor + lin. Q.

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

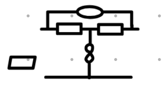
$\begin{bmatrix}\underline{u}\\ \underline{i}\end{bmatrix} = \begin{bmatrix}\underset{\sim}{u}\\ \underset{\sim}{i}\end{bmatrix}\cdot c + \begin{bmatrix}\underline{u_0}\\ \underline{i_0}\end{bmatrix}$

VCCS	$G=\begin{bmatrix}0 & 0\\ g & 0\end{bmatrix}$	$A=\begin{bmatrix}0 & -\frac{1}{g}\\ 0 & 0\end{bmatrix}$
VCVS	$H=\begin{bmatrix}0 & 0\\ \mu & 0\end{bmatrix}$	$A=\begin{bmatrix}\frac{1}{\mu} & 0\\ 0 & 0\end{bmatrix}$
CCCS	$H=\begin{bmatrix}0 & 0\\ \beta & 0\end{bmatrix}$	$A=\begin{bmatrix}0 & 0\\ 0 & -\frac{1}{\beta}\end{bmatrix}$
CCVS	$R=\begin{bmatrix}0 & 0\\ r & 0\end{bmatrix}$	$A=\begin{bmatrix}0 & 0\\ \frac{1}{r} & 0\end{bmatrix}$

NIK

$R_1 = -R_2$

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



Lin. 2-Tore

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

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 ⇒ b = c

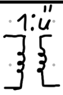
H ⇒ b = −c

A ⇒ Det = 1

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

Nullor = gesd. Q.

1 : ü



Übertrager Rez. & Verlustlos

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

Gyrator nicht Rez. & verlustlos

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

· $Tor_1 = Tor_2^d$

Sp. Teiler	Str. Teiler
$u_1 = \frac{R_1}{R_g}\cdot u_g$	$i_1 = \frac{g_1}{g_g}\cdot i_g$

$i_{1lin} = \underbrace{\frac{\partial g_1(u_1,u_2)}{\partial u_1}\Big|_{\underline{u}=\underline{U}}(u_1-U_1)+\frac{\partial g_1(u_1,u_2)}{\partial u_2}\Big|_{\underline{u}=\underline{U}}(u_2-U_2)}_{\Delta i_1}+I_1$

$i_{2lin} = \underbrace{\frac{\partial g_2(u_1,u_2)}{\partial u_1}\Big|_{\underline{u}=\underline{U}}(u_1-U_1)+\frac{\partial g_2(u_1,u_2)}{\partial u_2}\Big|_{\underline{u}=\underline{U}}(u_2-U_2)}_{\Delta i_2}+I_2$

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

2-Tor lin

↓

Lin. nicht Q-frei 2-Tor