Allgemein

Formeln

$u = R \cdot i$	$i = G \cdot u$
$R = \frac{u}{i}$	$G = \frac{i}{u}$
$P = R \cdot i^2$	$P = G \cdot u^2$

Parallel	Serie
$u_1 = u_2$	$u_1 + u_2$
$i_1 + i_2$	$i_1 = i_2$
$R_1 \parallel R_2$	$R_1 + R_2$
$G_1 + G_2$	$G_1 \parallel G_2$

Sp.-Teiler ·Serie

$u_1 = \frac{R_1}{R_1+R_2} \cdot u_g$

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

Str.-Teiler ·Parallel

$i_1 = \frac{G_1}{G_1+G_2} \cdot i_g$

$i_1 = \frac{R_2}{R_1+R_2}$

Dioden

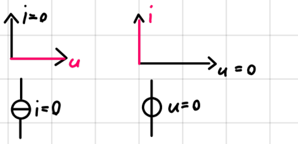
Ideal	pn
$u<0, i=0$	$i_d = I_s \cdot (e^{u_D/u_T} + 1)$
$u=0, i>0$	$u_d = U_T \cdot \ln(\frac{i_d}{I_s} + 1)$

KS-LL

$u', i' =$ Quelle

$u, i =$ Last

LL KS



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

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

Schalter $\begin{cases} 1, zu, KS \\ 0, auf, LL \end{cases}$ Q-frei $= (0,0)$

Generell

$i = \Sigma$ Str. = Par. St. Q

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

Lin. Quellen

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

$= G u' - i_0$

Ableitungsregeln

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

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

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

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

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

$x' = 1$

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

$k' = 0$

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

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

Inv. Matrix

$\begin{bmatrix} a & b \\ c & d \end{bmatrix}$

$det = ad - bc$

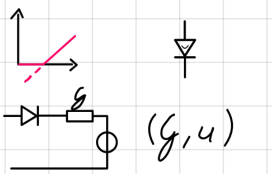
$A^{-1} = \frac{1}{det} \cdot \begin{bmatrix} d & -b \\ -c & a \end{bmatrix}$

Steigung

$\frac{Rise}{Run}$

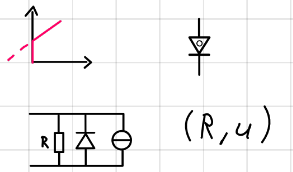
Eintore

Konkaver Widerstand



(G, u)

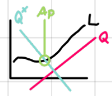
Konvexer Widerstand



(R, u)

Ap finden

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

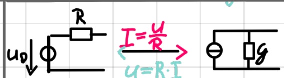


Umpolung

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

$r_{\mathcal{F}'}(i') = -r_{\mathcal{F}}(-i')$

Quellwandlung



$I = \frac{U}{R}$

$U = R \cdot I$

Linearisierung

$u_{lin} = \frac{\delta r_F(i)}{\delta i}\Big|_{i=I} \cdot (i - I) + U$ $\quad U = r_F(I)$

$i_{lin} = \frac{\delta g_F(u)}{\delta u}\Big|_{u=U} \cdot (u - U) + I$

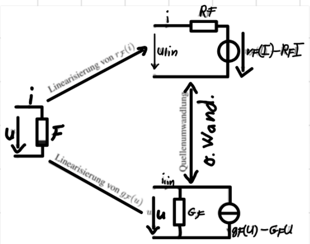


Abbildung 3.33: Linearisierung eines nichtlinearen Eintors $\mathcal{F}$

Zweitore

str. lin. & Q. frei

- 2 lin. un. Messungen
- Kernbesch. immer
- Bildbesch → 2 Mess.

lin. & Q. frei

-str. lin. 2-Tor + lin. Q.

$F = [M, N] \cdot \begin{bmatrix} u - u_0 \\ i - i_0 \end{bmatrix}$ 3 Mess.

$\begin{bmatrix} u \\ i \end{bmatrix} = \begin{bmatrix} U \\ I \end{bmatrix} \cdot c + \begin{bmatrix} u_0 \\ i_0 \end{bmatrix}$

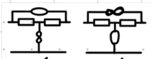
KS-LL

$x_{11} = \frac{1. gest.}{1. st.}\Big|_{2. st = 0}$

$x_{12} = \frac{1. gest.}{2. st.}\Big|_{1. st = 0}$

⋮

NIK



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

Nullor

$\} \{ =$ gest. Q.

VCVS

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

VCCS

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

CCCS

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

CCVS

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

Symmetrie

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

symm. if

$M = P \cdot M \cdot P$

Rez.

$R \& G \to b = c$

$H \to b = -c$

$A \to Det = 1$

$U^T \cdot I - I^T \cdot U = 0$

Verlustlos

$U^T \cdot I + I^T \cdot U = 0$

Jacobus Mat.

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

Dualw. 2-Tor

$G^d = \frac{1}{Rd^2} \cdot R$

$R^d = Rd^2 \cdot G$

Bild Besch.

$\begin{bmatrix} u \\ i \end{bmatrix} = \begin{bmatrix} u_1^1 & u_1^2 \\ u_2^1 & u_2^2 \\ i_1^1 & i_1^2 \\ i_2^1 & i_2^2 \end{bmatrix} \cdot \begin{bmatrix} c_1 \\ c_2 \end{bmatrix}$

Gyr. nicht Rez. & verlustlos

$R = -R^T$ $R = \begin{bmatrix} 0 & -Rd \\ Rd & 0 \end{bmatrix}$

$A = \begin{bmatrix} 0 & +Rd \\ \frac{1}{Rd} & 0 \end{bmatrix}$ $T_1 = T_2^d$

Übertrager Rez & verlustlos

1:ü

$U^T \cdot I = 0$

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

Kleinsignalanalyse

$\Delta i = i_{lin} - I_{AP}$ $\Delta u = u - U_{AP}$

Konst Q. = 0

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

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

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

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

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

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

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

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

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

*	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