# 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**: $u_1 = u_2$, $i_1 + i_2$, $R_1 \| R_2$, $G_1 + G_2$

**Serie**: $u_1 + u_2$, $i_1 = i_2$, $R_1 + R_2$, $G_1 \| G_2$

**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: $u<0, i=0$; $u=0, i>0$

pn: $i_d = I_S \cdot (e^{u_D/u_T} + 1)$; $u_d = U_T \cdot \ln(\frac{i_d}{I_S} + 1)$

## KS-LL

$u', i'$ = Quelle

$u, i$ = Last

**LL**: $i=0$

**KS**: $u=0$

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

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

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

## Generell

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

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

**Lin. Quellen**

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

$= G u' - i_0$

## Ableitungsregeln

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

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

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

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

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

$x' = 1$

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

$k' = 0$

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

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

**Inv. Matrix**

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

$\det = ad - bc$

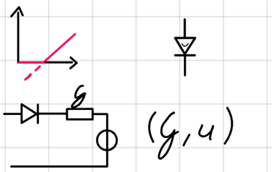
$A^{-1} = \frac{1}{\det} \cdot \begin{bmatrix} d & -b \\ -c & a \end{bmatrix}$

**Steigung**

$\frac{\text{Rise}}{\text{Run}}$

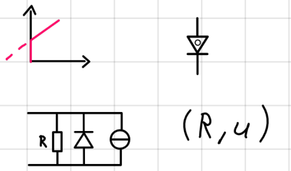
# Eintore

## Konkaver Widerstand



$(G, u)$

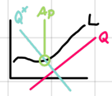
## Konvexer Widerstand



$(R, u)$

## Ap finden

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



## Umpolung

$g_{F'}(u') = -g_F(-u)$

$r_{F'}(i') = -r_F(-i')$

## Quellwandlung

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

$U = R \cdot I$

## Linearisierung

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

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

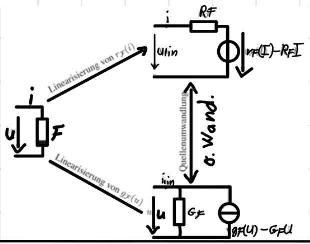



Abbildung 3.33: Linearisierung eines nichtlinearen Eintors $\mathcal{F}$

# Zweitore

**str. lin. & Q. frei**

- 2 lin. un. Massungen
- Kennbesch. 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**

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

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

⋮

**NIK**

$n = -1$ $\quad n = +1$

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

**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**

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

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

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

**Verlustlos**

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

**Jacobus Mat.**

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

**Dualw. 2-Tor**

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

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

**Bild Besch.**

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

**Gyr.**

nicht Rez. & verlustlos

$\underset{\sim}{R} = -\underset{\sim}{R}^T$

$R = \begin{bmatrix} 0 & -R_d \\ R_d & 0 \end{bmatrix}$

$A = \begin{bmatrix} 0 & +R_d \\ \frac{1}{R_d} & 0 \end{bmatrix}$

$T_2^d$

**Übertrager** Rez & verlustlos

$1 : \ddot{u}$

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

$\underset{\sim}{H} = \begin{bmatrix} 0 & \ddot{u} \\ -\ddot{u} & 0 \end{bmatrix}$ $A = \begin{bmatrix} \ddot{u} & 0 \\ 0 & \frac{1}{\ddot{u}} \end{bmatrix}$

**Kleinsignalanalyse**

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

Konst Q. = 0

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

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

$\underbrace{\qquad\qquad}_{\Delta i_1}$

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

$\underbrace{\qquad\qquad}_{\Delta i_2}$

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

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

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

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

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

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

| * | 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 |