$d \ll \lambda = \frac{c}{f}$, $c = 3\cdot 10^8 \frac{m}{s}$
mind Faktor 10

KCL: heraus ⊕, rein ⊖ } Knoteninzidenzmatrix
$(n-1)$
$\hookrightarrow A i = 0$

Baum: Superknoten, vorzeichen nach Baumknoten
$\hookrightarrow [1, A_v] \cdot i = 0$
$i = B^T i_v \mid u = A^T u_b$

Graph: Verbindungsstruktur
Baum: - alle Knoten - keine Schleifen
- zusammenhängend

KVL: $b-(n-1)$
$$\begin{bmatrix} 1 & 1 \\ 1 & 0 \\ 0 & 1 \end{bmatrix}\begin{bmatrix} u_{u1} \\ u_{u2} \end{bmatrix} = \begin{bmatrix} u_1 \\ u_2 \\ u_3 \end{bmatrix}$$

Baum: Schleifen mit nur 1 Verbindungszweig
$\hookrightarrow [B_b, 1] \cdot u = 0$

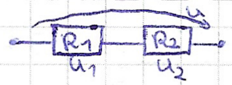
$M = A^T$ (Inzidenz) ; $A_v = -B_b^T$ (Baum) | Bild: $u = M \cdot u_u$

- aktiv: $u \cdot i < 0$ (1 Punkt in II o. IV)
- passiv: $u \cdot i > 0$ (nur in I u. III)
$\hookrightarrow$ verlustfrei: $u \cdot i = 0$ (Kennlinie Achsen)
$\hookrightarrow$ verlustbehaftet: (mind 1 nicht auf Achsen)

resistive Eintore:
implizit: $u - Ri = 0$
parametrisch: $u = u_F(\lambda)$
explizit: $u = r_F \cdot i$

Eigenschaften: - ungepolt (Punktsymetrie)
- Quellenfrei: Ursprung, keine Quellen
- Strom/Spannungsg.: Jedem Strom/Spannungswert nur 1 wert
- streng linear: Ursprungsgerade (≠ Nullator / Norator)
- linear: jede Gerade
- stückweise linear: aus Geradenstücken

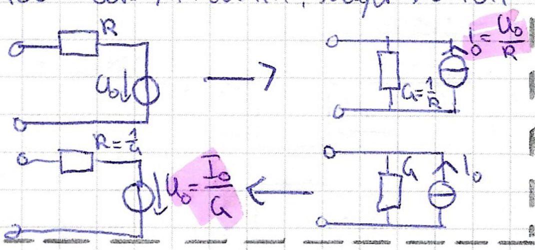
Dualität:
$u \to R_d i$ $\quad i \to \frac{u}{R_d}$
$R^d = \frac{R_d^2}{R}$ $\quad G^d = \frac{1}{R_d^2 G}$


$u_1 = \frac{R_1}{R_1+R_2} u$
-> Addition Spannungswerte

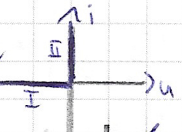

$i_1 = \frac{G_1}{G_1+G_2} i$
-> Addition v. Stromwerten

$G = \frac{i_0}{u_0}$ $\quad R = \frac{u_0}{i_0}$

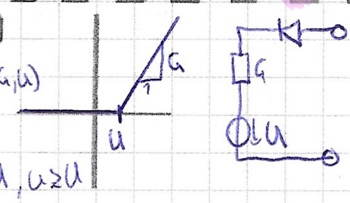
Quellwandlung:
Helmholtz-/Thevenin : Mayer-Norton


$i_0 = \frac{u_0}{R}$, $G = \frac{1}{R}$, $R = \frac{1}{G}$, $u_0 = \frac{I_0}{G}$

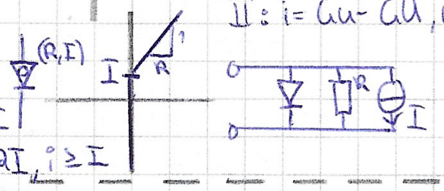
Ideale Diode
I: $i = 0, u \le 0$
II: $u = 0, i \ge 0$



Konkav: (G, U)
I: $i = 0$ $u \le U$
II: $i = Gu - GU$, $u \ge U$



Konvex: (R, I)
I: $u = 0, i \le I$
II: $u = Ri - RI$, $i \ge I$



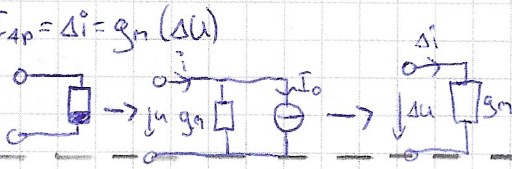
$i_D = I_S \exp\left(\frac{u_D}{U_T} - 1\right)$
$u_D = U_T \ln\left(\frac{i_D}{I_S} + 1\right)$

$u(t) = U_{AP} + \Delta u \quad / \quad i(t) = I_{AP} + \Delta i$

Arbeitspunktbest.:
graphisch: Schnittpunkt Quelle & Last Kennlinie -> KS-/LL-Methode
$\hookrightarrow Q^x$ -> spiegelung an u Achse
rechnerisch: Quelle & Last gleichsetzen

Linearisierung: $i_{F,lin} = \frac{\partial i_F}{\partial u_F}\Big|_{AP} (u_F - U_{AP}) + I_{AP}$ $\qquad u_{F,lin} = \frac{\partial u_F}{\partial i_F}\Big|_{AP} \cdot (i_F - I_{AP}) + U_{AP}$

Großsignal: Parallelsch. v. ~~Widerstand~~ Leitwert & Stromquelle; Serienschaltung v. R und Spannungsquelle
(si ∧ su weggelassen)
Kleinsignal: - Konst. Quellen zu null
- alle Beschreibungen ein Δ
$i - I_{AP} = \Delta i = g_n (\Delta u)$



Mind. Leitwert: $G_i \ge \| G_L \|$

Resistive Zweitore
$\begin{bmatrix} i_1 \\ i_2 \end{bmatrix} = G \begin{bmatrix} u_1 \\ u_2 \end{bmatrix}$
$\begin{bmatrix} u_1 \\ u_2 \end{bmatrix} = R \begin{bmatrix} i_1 \\ i_2 \end{bmatrix}$
$\begin{bmatrix} u_1 \\ i_2 \end{bmatrix} = H \begin{bmatrix} i_1 \\ u_2 \end{bmatrix}$
$\begin{bmatrix} i_1 \\ u_2 \end{bmatrix} = H' \begin{bmatrix} u_1 \\ i_2 \end{bmatrix}$
$\begin{bmatrix} u_1 \\ i_1 \end{bmatrix} = A \begin{bmatrix} u_2 \\ -i_2 \end{bmatrix}$
$\begin{bmatrix} u_2 \\ i_2 \end{bmatrix} = A' \begin{bmatrix} u_1 \\ -i_1 \end{bmatrix}$

implizit:
$Mu + Ni = 0$
Bsp: $1u - Ri = 0$
-> $[1, -R]\begin{bmatrix} u \\ i \end{bmatrix} = 0$
(Kern)

parametrisch
Betriebsmatrix
$C \begin{bmatrix} U \\ I \end{bmatrix} = \begin{bmatrix} u_1 & u_1 \\ u_2 & u_2 \\ i_1 & i_1 \\ i_2 & i_2 \end{bmatrix}$
(Bild)

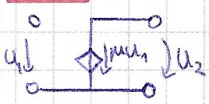
-> 2 linear unabhängige Messungen (+1 falls Quelle) -> KS-/LL-Methode (abwechselnd)
1) Matrix quellenfrei bestimmen
2) Quellvektor best. (Beide steuernden Größen zu 0)
3) Schaltung mit externen Quellen zeichnen

Linearisierung:
$$\begin{bmatrix} u_1 \\ u_2 \end{bmatrix} = Z_{AP} \begin{bmatrix} i_1 - I_1 \\ i_2 - I_2 \end{bmatrix} + \begin{bmatrix} U_1 \\ U_2 \end{bmatrix}$$

Eigenschaften:

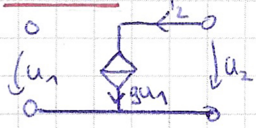
- Leistungsbilanz: $p(t) = u^T i = p_1(t) + p_2(t)$
- Verlustlos: $u^T i = 0$
  $\rightarrow G = -G^T,\ R = -R^T$
  $\rightarrow U^T I + I^T U = 0$
- aktiv: $u^T i < 0$
- passiv: $u^T i \geq 0$
- Symmetrie / Umkehrbarkeit: $A = A'$
  Vertausch d. Tore ändert nichts
  $G = \underset{\sim}{P}\,\underset{\sim}{G}\,\underset{\sim}{P}$, $R = \underset{\sim}{P}\,\underset{\sim}{R}\,\underset{\sim}{P}$, $P = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$
- Reziprozität (Übertragungssymmetrie)
  $\underset{\sim}{R} = \underset{\sim}{R}^T \quad \underset{\sim}{G} = \underset{\sim}{G}^T$
  $\frac{u_1}{i_2} = \frac{u_2}{i_1} \quad h_{12} = -h_{21} \quad h'_{12} = -h'_{21} \quad U^T I - I^T U = 0$
  $\det(A) = 1 \quad \det(A') = 1$

VCVS:



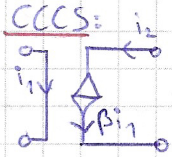
$H' = \begin{pmatrix} 0 & 0 \\ \mu & 0 \end{pmatrix}$ $A = \begin{pmatrix} \frac{1}{\mu} & 0 \\ 0 & 0 \end{pmatrix}$

VCCS:



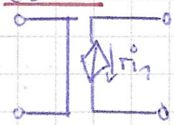
$G = \begin{pmatrix} 0 & 0 \\ g & 0 \end{pmatrix}$ $A = \begin{pmatrix} 0 & -\frac{1}{g} \\ 0 & 0 \end{pmatrix}$

CCCS:



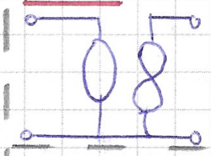
$H = \begin{pmatrix} 0 & 0 \\ \beta & 0 \end{pmatrix}$ $A = \begin{pmatrix} 0 & 0 \\ 0 & -\frac{1}{\beta} \end{pmatrix}$

CCVS:



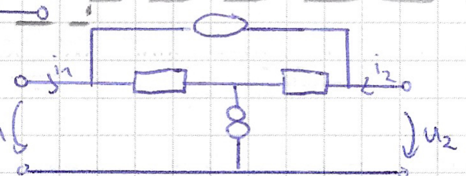
$R = \begin{pmatrix} 0 & 0 \\ r & 0 \end{pmatrix}$ $A = \begin{pmatrix} 0 & 0 \\ \frac{1}{r} & 0 \end{pmatrix}$

Nullor



$M = \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix}$ $N = \begin{pmatrix} 0 & 0 \\ 1 & 0 \end{pmatrix}$ $A = \begin{pmatrix} 0 & 0 \\ 0 & 0 \end{pmatrix}$

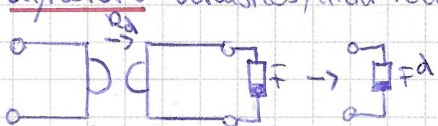
NIK:



$H = \begin{pmatrix} 0 & -k \\ -k & 0 \end{pmatrix}$

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

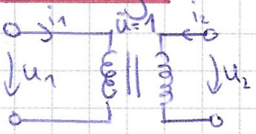
Gyrator: verlustlos, nicht reziprok



$\underset{\sim}{R} = \begin{bmatrix} 0 & -R_d \\ R_d & 0 \end{bmatrix}$ $\underset{\sim}{G} = \begin{bmatrix} 0 & G_d \\ -G_d & 0 \end{bmatrix}$

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

Übertrager: verlustlos & reziprok



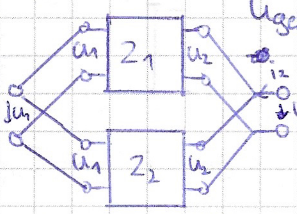
$R = 0,\ G = 0$

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

$R_{ü} = ü^2 R$ (an Tor 2 R angeschlossen)

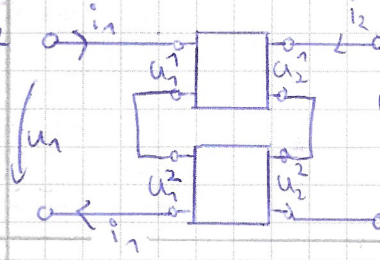
Verschaltung

- parallel:



$G_{ges} = G_{21} + G_{22}$

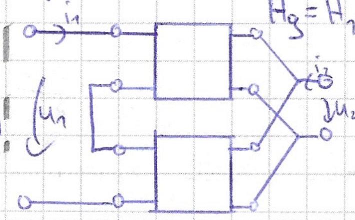
- serien



$R_{ges} = R + R$

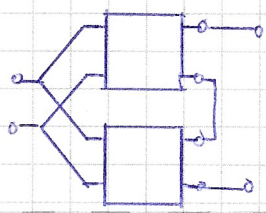
serie-parallel

~~parallel-serie~~



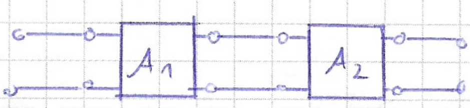
$H_g = H_1 + H_2$

~~serie-parallel~~ parallel-serie



$H'_g = H'_1 + H'_2$

Kettenversch:



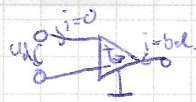
$A_{ges} = A_1 \cdot A_2$
$A'_{ges} = A'_2 \cdot A'_1$

Geg.

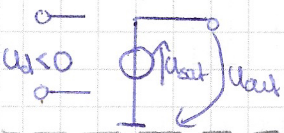
Gesucht

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

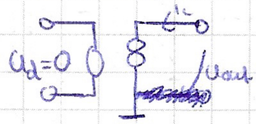
OP-Amps:



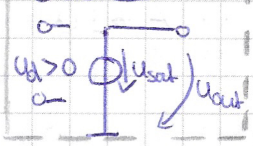
ESB I:



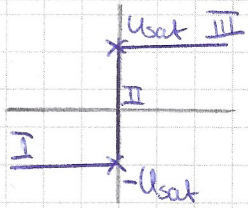
ESB II



ESB III



Kennlinie:



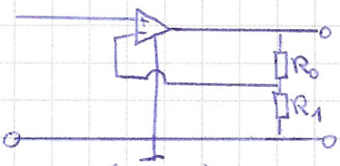
Gleichungen:

I: $u_d<0$, $u_{out}=-U_{sat}$

II: $u_d=0$, $|u_{out}|\le|U_{sat}|$

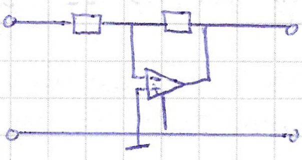
III: $u_d>0$, $u_{out}=U_{sat}$

Nicht invertierender Verstärker



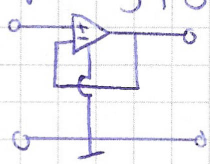
$u_{out}=\left(1+\frac{R_0}{R_1}\right)u_{in}$

Invertierender Verstärker



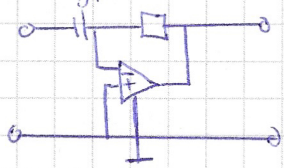
$u_{out}=-\frac{R_0}{R_1}u_{in}$

Spannungsfolger



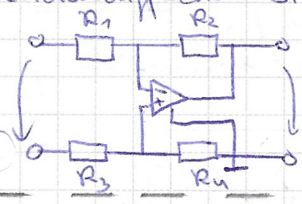
$u_{out}=u_{in}$

Differenzierer



$u_{out}=-RC\cdot u_{in}$

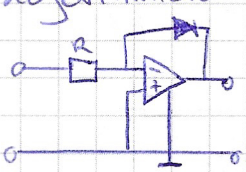
Potenzialdifferenzverstärker



$u_{out}=-\frac{R_2}{R_3}u_{in}$

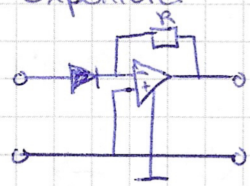
$=-\frac{R_4}{R_3}u_{in}$

Logarithmierer



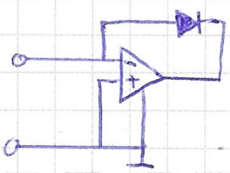
$u_{out}=-U_T\ln\frac{u_{in}}{R\cdot I_s}$

exponierer

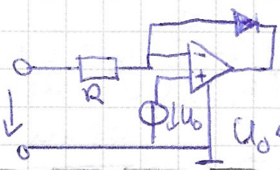


$u_{out}=-RI_s\exp\left(\frac{u_{in}}{U_T}\right)$

Ideale Diode

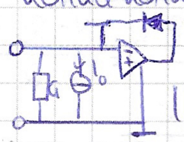


Konkaver Widerstand



$U_0<U_{sat}$

~~Konka~~ Konvex



$I_0<G\cdot U_{sat}$

~~Reduzierte Knotensp.analyse:~~

~~1) nicht U-gesteuerte Q. wandeln~~

	Matrix	Vektor
Stromrichtung:	rein neg.	rein pos
	raus pos	raus neg

~~Reduz. Knotensp.~~ Knoten G_L

1) Wandeln – Quellwandeln (mit Trick) (auch gesteuert)

– Dualwandlung mit Gyrator

Mehrtore

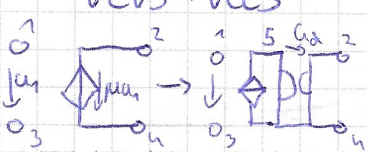
- Dreitorzirkulator (verlustlos & nicht rezi)

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

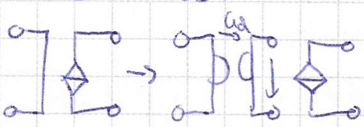
- Mehrtorübertrager

$$\begin{bmatrix}i_1\\ u_2\\ \vdots\\ u_p\end{bmatrix}=\begin{bmatrix}0 & -\frac{1}{ü_2} & \cdots & -\frac{1}{ü_p}\\ \frac{1}{ü_2} & 0 & & \\ \vdots & & \ddots & \\ \frac{1}{ü_p} & & & \end{bmatrix}$$

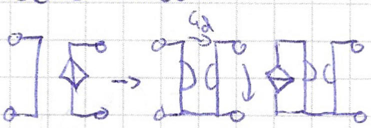
VCVS -> VCCS



CCCS -> VCCS



CCVS -> VCCS

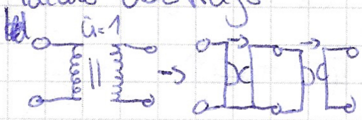


$\alpha=\frac{i_1}{G_d}$

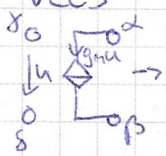
$i_2=G_d u$

$u_2=-G_d\frac{1}{G_d^2}i_1$

Idealer Übertrager



VCCS



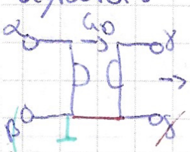
$$Y_k=\begin{array}{cc|c} \gamma & \delta & \\ \hline g_m & -g_m & \alpha\\ -g_m & g_m & \beta\\ \vdots & \vdots & \end{array}$$

2) Knoten nummerieren

3) Aufstellen d. Knotenleitwertsmatrix

α o–[G]–o β $\quad Y_k=\begin{array}{cc|c}\begin{bmatrix}G & -G\\ -G & G\end{bmatrix} & & \begin{matrix}\alpha\\ \beta\end{matrix}\\ \alpha\ \ \beta & & \end{array}$

Gyrator:



$$Y_k=\begin{array}{c|cccc} & \alpha & \beta & \gamma & \delta\\ \hline \alpha & \cdots & \cdots & G_d & -G_d\\ \beta & \cdots & \cdots & -G_d & G_d\\ \gamma & -G_d & G_d & \cdots & \cdots\\ \delta & G_d & -G_d & \cdots & \cdots \end{array}$$

4) Quellvektor

$$\rightarrow \begin{array}{c}\alpha\\ \beta\end{array}\begin{bmatrix}-I_0\\ +I_0\end{bmatrix}$$

5) Streichen

o—o o—o Zeile add + streichen

o—o Spalte add + streichen

Tableaugleichungen

- KVL: $Bu=0$
- KCL: $Ai=0$
- Bauteile: $Mu+Ni=0$

$\Big\} \rightarrow \begin{bmatrix} B & 0 \\ 0 & A \\ M & N \end{bmatrix} \begin{bmatrix} u \\ i \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ e \end{bmatrix}$

Knotenspannungsanalyse

$$\begin{bmatrix} -A^T & 1 & 0 \\ 0 & 0 & A \\ 0 & M & N \end{bmatrix} \cdot \begin{bmatrix} u_k \\ u \\ i \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ e \end{bmatrix}$$

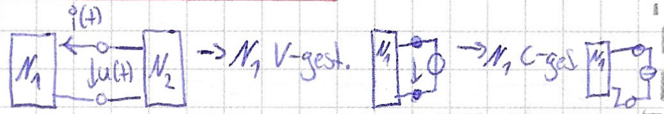
(KVL in Bildraum)

Maschenstromanalyse

$$\begin{bmatrix} B & 0 & 0 \\ 0 & 1 & -B^T \\ M & N & 0 \end{bmatrix} \begin{bmatrix} u \\ i \\ i_m \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ e \end{bmatrix}$$

(KCL in Bildraum)

Substitutionstheorem



Zweipolersatzschaltung

Bestimmung d. Bauteilwerte

1) über Kurzschluss / LL $\rightarrow R = -\frac{U_0}{I_0}$ $G = -\frac{I_0}{U_0}$

2) U_0 - LL / I_0 - KS

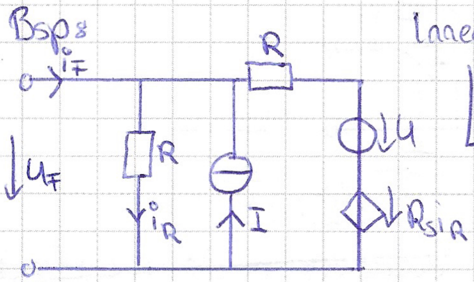
$\rightarrow$ alle unabh. Quellen zu null und u in abh. v. i berechnen

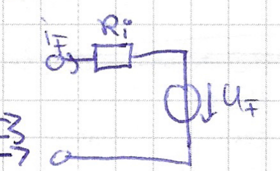
G_i / L_i — LL / KS

Superpositionsprinzip

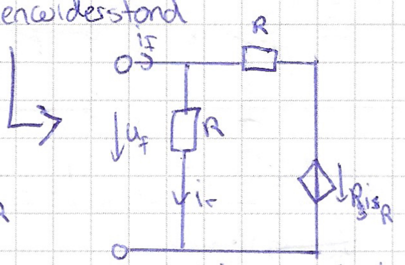
- lineare Schaltung
- jede Quelle zu Null bis auf eine
- $\rightarrow$ Summe der u ist gesamt u

Bsp:





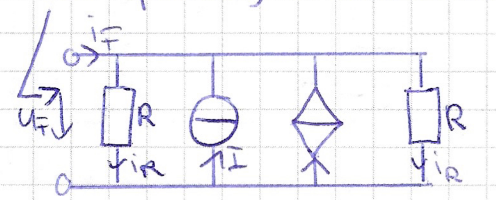
Innenwiderstand



$$i_F = i_R + \frac{u_F - R_s i_R}{R} = \frac{2 - R_s/R}{R} u_F$$

$$\boxed{R_i = \frac{u_F}{i_F} = \frac{R}{2 - R_s/R}}$$

LL-Spannung (+ Quellwandlung)



$$\left(2 - \frac{R_s}{R}\right) i_R = I + \frac{u}{R}$$

$$\left(2 - \frac{R_s}{R}\right) u_F = RI + u$$

$$\boxed{\rightarrow u_F = \frac{RI + u}{2 - \frac{R_s}{R}}}$$

Reaktanzen

Ladung $q(t) = \int_{-\infty}^{t} i(\tau)d\tau = q(t_0) + \int_{t_0}^{t} i(\tau)d\tau \rightarrow i(t) = \frac{dq(t)}{dt}$

Fluss $\Phi(t) = \int_{-\infty}^{t} u(\tau)d\tau = \Phi(t_0) + \int_{t_0}^{t} u(\tau)d\tau \rightarrow u(t) = \frac{d\Phi(t)}{dt}$

Streng linear

$q = Cu$ $\quad \Phi = Li$

$i = C\dot{u}$ $\quad u = L\dot{i}$

Einheit

~~[illegible]~~ $\frac{Q}{U} = 1\,\text{Farad} = 1F$ $\quad \frac{A}{V}s = S_s$

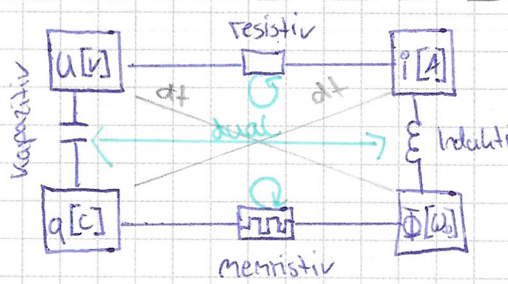
q: $C = As$

Φ: $Wb = Vs$

$\frac{\Phi}{A} = 1\,\text{Henry}$ $\quad \frac{Vs}{A} = \Omega s$

Eigenschaften:

- verlustfrei: Kennlinie hat keine Schleifen



- KS
- LL
- Nullor
- Nullator

$\rightarrow$ alle 4 Gruppen

- Energie: $W(t_0, t_1) = \int_{t_0}^{t_1} p(t)dt$

$W_C = \int_{q_1}^{q_2} u(q)dq$ $\quad W_L = \int_{\Phi_1}^{\Phi_2} i(\Phi)d\Phi$

Linear:

$W_C = \frac{1}{2}C(u_2^2 - u_1^2)$ $\quad W_L = \frac{1}{2}(i_2^2 - i_1^2)$

$E_C = \frac{1}{2}Cu^2$ $\quad E_L = \frac{1}{2}Li^2$

nicht linear

Kapazität	Induktivität
$q = c(u)$	$\Phi = l(i)$
$u = x(q)$	$i = \lambda(\Phi)$

~~Lineare~~ Dualität

~~[illegible]~~ $u \rightarrow R_d i^d$ $\quad i \rightarrow \frac{u^d}{R_d}$

$\Phi \rightarrow R_d q^d$ $\quad q \rightarrow \frac{\Phi}{R_d}$

Kapaz.: Parallel $C_1 + C_2$

Serie $C_1 \| C_2$

Indukt.: Parallel $L_1 \| L_2$

Serie $L_1 + L_2$

Memristor

$q = m(\Phi)$

$\Phi = \mu(q)$

Relaxationspunkte

= Ruhepunkte (gesp. Energie minimum)
1) · Schnittpunkte Achsen
· Knickpunkte
· Extremstellen

2) Energie aufnehmen, wenn bewegt von einem Relax. Punkt zu einem anderen

$w = \int u\,dq = \int i\,d\phi \geq 0$
→ Produkt muss > 0

Komplexe Wechselstromrechnung

1) Voraussetzungen

- lineares, zeitinvariantes System
- sinusförmige Wechselsp. o. Wechselstrom

→ alle Signal d. Schaltung sinusförmig mit gl. Frequenz

$I = \hat{I}\sin(\omega t) \hat{=} \hat{I}\cos(\omega t - \frac{\pi}{2})$

$U = \hat{U}\sin(\omega t) \hat{=} \hat{U}\cos(\omega t - \frac{\pi}{2})$

Zeiger Darstellung:

$a(t) = \hat{A}\cos(\omega t + \varphi) \leftrightarrow A = \hat{A}e^{j\varphi}$

$= Re\{\hat{A}e^{j(\omega t + \varphi)}\}$

Rechenregel:

$\frac{\partial}{\partial t} \leftrightarrow j\omega$: $u(t) = L\dot{i}(t) \hat{=} j\omega L I = U$

In $\mathbb{C}$: $a + jb = re^{j\varphi}$ $\quad z_1 + z_2 = (Re_1 + Re_2) + j(Im_1 + Im_2)$

$a - jb = re^{-j\varphi}$

Komplexe Leistung:

$P = \frac{1}{2}UI^* = \frac{1}{2}\hat{U}\hat{I}e^{j(\varphi_u - \varphi_i)}$ (bei Zeigern)

$P = P_W + jP_B$

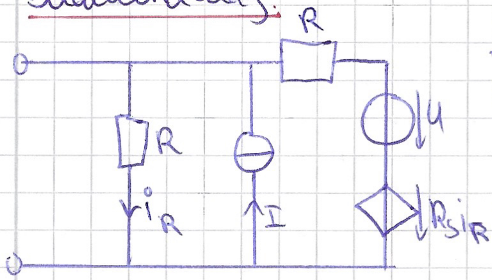
kompl. Leistung Scheinleistung:	Wirkleistung $= Re\{\frac{1}{2}UI^*\}$	Blindleistung $= Im\{\frac{1}{2}UI^*\}$
$S = \lvert P\rvert = \sqrt{P_W^2 + P_B^2}$	→ nur an resistiven Elementen	→ nur an reaktiven Elementen
	→ Mittelwert der Momentanleistung	→ physikalisch: Leistung die zum period

- Newton Raphson: $\begin{bmatrix} D & G \\ 0 & A \\ M' & N' \end{bmatrix}\begin{bmatrix} u \\ i \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ e \end{bmatrix}$ ← linearer Teil

1. Wähle Initialisierung $\begin{bmatrix} u^0 \\ i^0 \end{bmatrix}$ mit $f(u, i) = 0$
2. Im $n+1$-ten Schritt: Linearisiere $f(u, i) = 0$ im n-ten Kandidaten für den AP $\begin{bmatrix} u^n \\ i^n \end{bmatrix}$
3. Löse das neue GLS $\Rightarrow [\tilde{u}^{(n+1)T}, \tilde{i}^{(n+1)T}]^T$
4. finde den neuen Kandidaten für AP in der Nähe $[\tilde{u}^{(n+1)T}, \tilde{i}^{(n+1)T}]$ mit $f(u^{n+1}, i^{n+1}) = 0$

Abbruch: $\left\lVert \begin{bmatrix} u^{n+1} \\ i^{n+1} \end{bmatrix} - \begin{bmatrix} u^n \\ i^n \end{bmatrix} \right\rVert \leq \varepsilon$ (Toleranz, Genauigkeit)

Dualwandlung



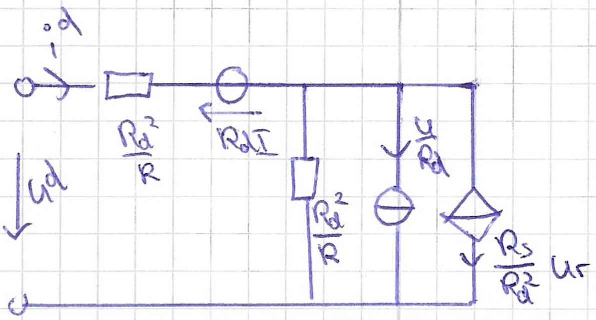
$Ri = u \to i = \frac{R}{R_d^2} u \to u = \frac{R_d^2}{R} i$

$u \to i = \frac{u}{R_d}$

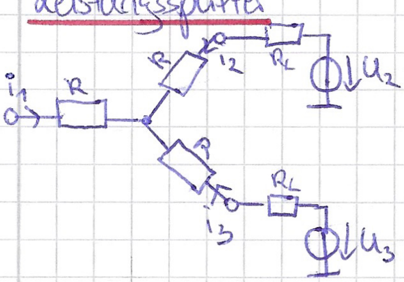
$I \to u = R_d I$

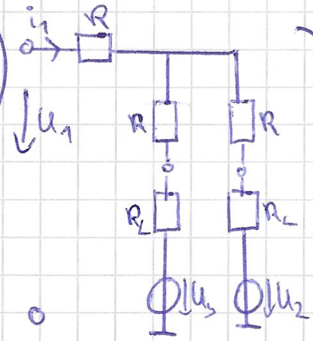
$u = R_s i_R$
$\to i = \frac{R_s}{R_d^2} u_R$

$\Rightarrow$

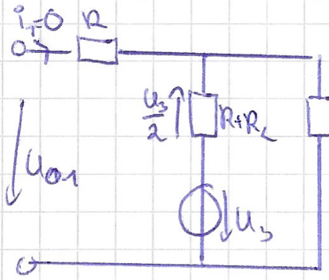


Leistungssplitter





Leerlaufsp. mit Superpositionsprinzip



$u_{01} = \frac{u_3}{2}$

$\hookrightarrow u_{02} = \frac{u_2}{2}$

$\hookrightarrow u_1 = \frac{u_3+u_2}{2}$

$R_i = \frac{3R+R_L}{2}$

$\mathring{i}_2$ = beliebig -> Existiert eine Inverse Kettenbeschreibung?

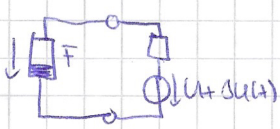
Nein, da i_2 nicht von den anderen Größen abhängt und somit steuert.

$$\begin{bmatrix} 1A & -2A \\ 0A & 1A \end{bmatrix} u + \begin{bmatrix} 1V & 0V \\ 0V & 1V \end{bmatrix} i = 0$$ $\Rightarrow$ in inverse Hybridbeschr.

$$\begin{bmatrix} 1A & 0V \\ 0A & 1V \end{bmatrix} \begin{bmatrix} u_1 \\ i_2 \end{bmatrix} + \begin{bmatrix} 1V & -2A \\ 0V & 1A \end{bmatrix} \begin{bmatrix} i_1 \\ u_2 \end{bmatrix}$$

$$H'_A = -\begin{bmatrix} 1V & -2A \\ 0V & 1A \end{bmatrix}^{-1} \begin{bmatrix} 1A & 0V \\ 0A & 1V \end{bmatrix} = \begin{matrix} -1S & -2 \\ 0 & -1\Omega \end{matrix}$$

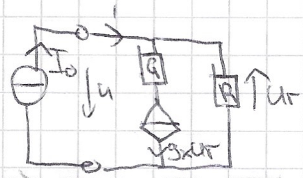
$i = \ln\left(\frac{u}{1V}+1\right) 1mA$ ↯ für Kleinsignalwert von F messen Sie $g_{ks} = 0{,}2mS$



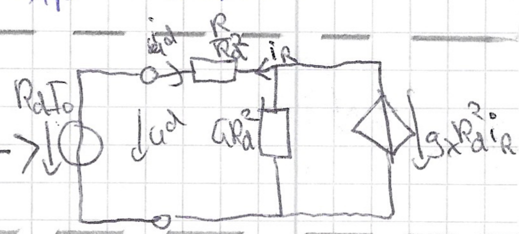
$\to \frac{\partial i}{\partial u}\Big|_{AP} = \frac{1mS}{1+\frac{u_{AP}}{1V}} = g_{ks}$

$\to U_Q = u_{AP} + R i_{AP} \to u_{AP} = \frac{1mS - g_{ks}}{g_{ks}} \cdot 1V = 4V$

$\to i_{AP} = \ln(5)\, mA$



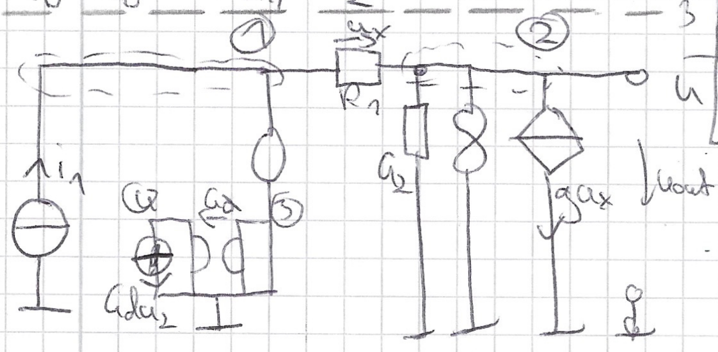
$\to$



G_B ges. Leiten Sie aus Bedingung d. Reziprozität eine Bed. für G_B her

$U^T I - I^T U = 0 \to U^T G_B U - U^T G_B^T I = 0$

$\to G_B = G_B^T \to G_1 = G_2$



$$\begin{array}{c|cccc} & 1 & 2 & 3 & 4 \\ \hline 1 & \frac{1}{R_1} & -\frac{1}{R_1} & & \\ 2 & -\frac{1}{R_1}+g & \frac{1}{R_1}+G_2-g & & \\ 3 & & & & G_d \\ 4 & & & -G_d & \end{array} \begin{bmatrix} u_{k1} \\ u_{k2} \\ u_{k3} \\ u_{k4} \end{bmatrix} = \begin{bmatrix} \mathring{i}_1 \\ \\ \\ -G_d u_2 \end{bmatrix}$$

$u_x = u_{k1} - u_{k2}$