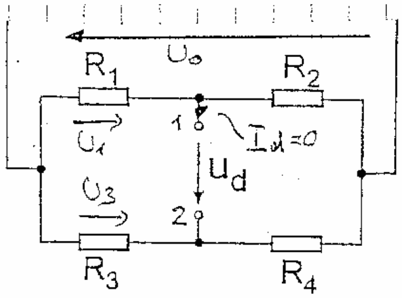
7.1 Gleichstrom- /Gleichspannungsbrücke

a)



$$U_d = U_3 - U_1$$

$$U_3 = U_0 \frac{R_3}{R_3+R_4}, \quad U_1 = U_0 \frac{R_1}{R_1+R_2}$$

$$\frac{U_d}{U_0} = \frac{R_2R_3 - R_1R_4}{(R_1+R_2)(R_3+R_4)}$$

b) Stromspeisung I_0

$$U_d = I_0 \frac{R_2R_3 - R_1R_4}{R_1+R_2+R_3+R_4}$$

c) 1/4-Brücke → 1 Sensor

1/2-Brücke → 2 "

Voll-Brücke → 4 "

d) DMS: Zug-DMS → "+"

Druck-DMS → "−"

Pt: → "+"

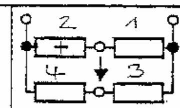
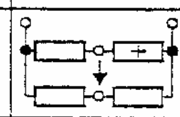
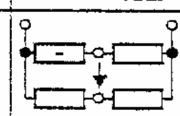
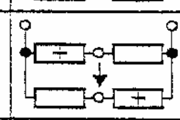
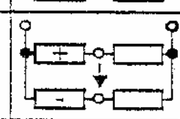
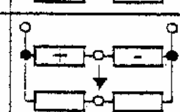
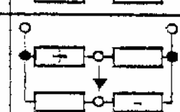
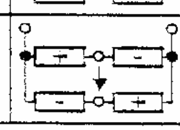
e) Vergleich mit 1/4-Brücke:

- 1/2-B: (f) doppelte Empf., Temperatur-Komp.
- 1/1-B: (f) 4-fache Empfindl., Temp.-kompens.

f) $U_d = \frac{U_0}{2} \frac{\Delta R}{R_0}$

exakt, keine Näherung

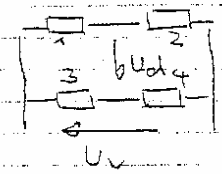
d)

	U_0-gespeist	I_0-gespeist
	$U_d \approx \frac{U_0}{4}\frac{\Delta R}{R_0}$	$U_d \approx \frac{I_0}{4}\Delta R$
	$U_d \approx -\frac{U_0}{4}\frac{\Delta R}{R_0}$	$U_d \approx -\frac{I_0}{4}\Delta R$
	$U_d \approx -\frac{U_0}{4}\frac{\Delta R}{R_0}$	$U_d \approx -\frac{I_0}{4}\Delta R$
	$U_d \approx \frac{U_0}{2}\frac{\Delta R}{R_0}$	$U_d = \frac{I_0}{2}\Delta R$
	$U_d \approx \frac{U_0}{2}\frac{\Delta R}{R_0}$	$U_d = \frac{I_0}{2}\Delta R$
	$U_d = \frac{U_0}{2}\frac{\Delta R}{R_0}$	$U_d = \frac{I_0}{2}\Delta R$
	$U_d \approx -\frac{U_0}{4}\left(\frac{\Delta R}{R_0}\right)^2$	$U_d = -\frac{I_0}{4}\frac{\Delta R}{R_0}\Delta R$
	$U_d = U_0\frac{\Delta R}{R_0}$	$U_d = I_0\Delta R$

7.2 Brückenschaltung

a) $U_d = U_4 - U_2 = U_V\left(\frac{R_4}{R_3+R_4} - \frac{R_2}{R_1+R_2}\right) = U_V \frac{R_1R_4 - R_2R_3}{(R_1+R_2)(R_3+R_4)}$

mit $R_1 = R_3 = R_4 = R$ und $R_2 = R$



$$\underline{\underline{\frac{U_d}{U_V}}} = \frac{RR - RR_x}{(R+R_x)2R} = \underline{\underline{\frac{-1}{2}\frac{R_x - R}{R+R_x}}} \left(= \frac{1}{2}\,\frac{1-{R_x}/{R}}{1+{R_x}/{R}}\right)$$

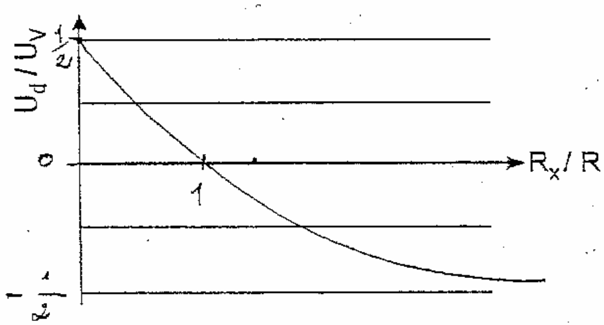
$= \underline{\underline{A}}$

b) $E = \frac{d(U_d/U_V)}{d(R_x/R)}$ mit $\frac{U_d}{U_V} = \frac{1-x}{1+x}$ $x = {R_x}/{R}$

$$\underline{\underline{E}} = \frac{1}{2}\,\frac{-2}{(1+x)^2} = -\frac{1}{(1+x)^2} \quad \text{mit } \underline{x = {R_x}/{R}}$$

$\underline{\underline{E(0) = -1}}$; $\underline{\underline{E(\infty) = 0}}$

c)

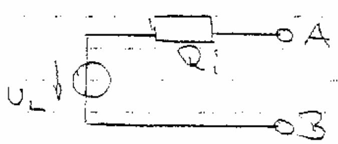


$R_x/R = 0 \rightsquigarrow {U_d}/{U_V} = +\frac{1}{2}$

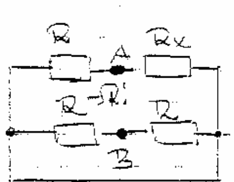
$R_x/R = 1 \rightsquigarrow \quad = 0$

$R_x/R \to \infty \rightsquigarrow \quad = -\frac{1}{2}$

d) $\underline{\underline{{U_d}/{U_V}}} = \frac{1}{2}\,\frac{R-(R+\Delta R)}{R+(R+\Delta R)} = \frac{1}{2}\,\frac{(-\Delta R)}{2R+\Delta R} \approx \underline{\underline{-\frac{1}{4}\,\frac{\Delta R}{R}}}$



$\underline{\underline{U_L = U_d}}$ nach a)



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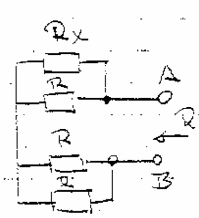
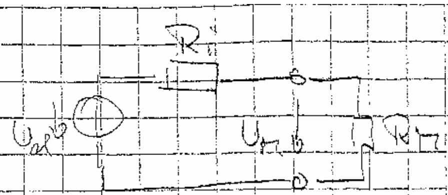


$R_i = R_x \| R + R \| R$

$$\underline{\underline{R_i = \frac{R_x R}{R_x + R} + \frac{R}{2}}}$$

e)



$$\frac{U_M}{U_d} = \frac{R_M}{R_i+R_M} = \frac{1}{1+R_i/R_M} \approx 1 - \frac{R_i}{R_M}$$

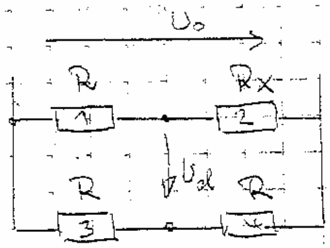
(für $\ll 1$)

$$F_{rel} = \frac{U_M - U_d}{U_d} = \frac{U_M}{U_d} - 1 \approx -\frac{R_i}{R_M}$$

$$R_i = \frac{R_x R}{R_x+R} + \frac{R}{2} \approx 100\Omega$$

$$R_M \geq \left|\frac{R_i}{F_{rel}}\right| = \frac{100\Omega}{0{,}01} = 10k\Omega$$

f) U_0 - Viertelbrücke (1/4 ~)

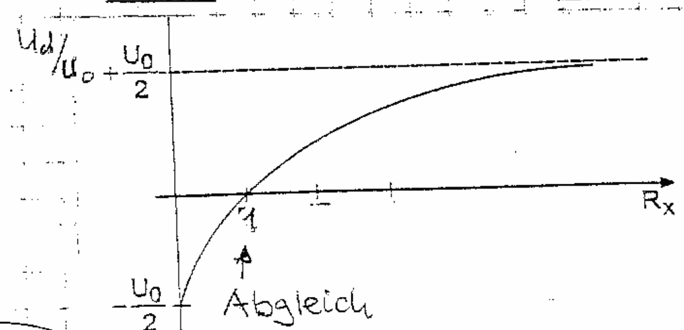


hier: $R_2 = R_x$; $R_1 = R_3 = R_4 = R$

aus (1):

$$U_d/U_0 = \frac{R_x R - RR}{(R_x+R)(R+R)} = \frac{1}{2} - \frac{1}{1+R/R_x}$$

($U_V \equiv U_0$)



bei 1 Sensor ($R_x = R + \Delta R$):

$$U_d/U_0 = \frac{\Delta R}{2R+\underbrace{\Delta R}_{\ll R}}\cdot\frac{1}{2} \approx \frac{1}{4}\frac{\Delta R}{R}$$

g)

	Sensor 1	Sensor 2
Sensorbezeichnung	DMS	Pt100
Meßgröße M	Dehnung ε	Temperatur ϑ
Einheit der Meßgröße	/	°C
Meßbereich incl. Einheit	einige ‰	-200°C ... 600°C
R_0 zahlenmäßig incl. Einheit	120Ω	100Ω
E zahlenmäßig incl. Einheit	$E = \frac{\partial R}{\partial \varepsilon} = R_0 k$ in Ω	$E = \frac{\partial R}{\partial \vartheta} = R_0 \alpha$ in $\frac{\Omega}{K}$

7.3 Heissleiter (NTC)

a) $\frac{\partial R}{\partial T} = -\frac{1}{T^2} R_0 e^{b/T}$

b)

7.4 Wechselstrombrücke

a) $\underline{U_d} = U_0 \frac{Z_1 Z_4 - Z_2 Z_3}{(Z_1 + Z_2)(Z_3 + Z_4)}$

b) $\underline{Z}_1 = j\omega(L_0 + \Delta L)$; $\underline{Z}_2 = j\omega(L_0 - \Delta L)$; $\underline{Z}_3 = R_0$; $\underline{Z}_4 = R_0$

$\underline{\underline{\frac{U_d}{U_0}}} = \frac{1}{2} \frac{\Delta L}{L_0}$; keine Frequenzabhängigkeit

c) $U_d = 0$: $\underline{Z}_1 \underline{Z}_4 \overset{!}{=} \underline{Z}_2 \underline{Z}_3$ ⇝ komplex ⇝ 2 Abgleichbedingungen

wegen $\underline{Z} = |Z| e^{j\varphi}$ | wegen $\underline{Z} = Re + j\,Im$

$|\underline{Z}_1| \cdot |\underline{Z}_4| = |\underline{Z}_2| \cdot |\underline{Z}_3|$ | $Re\{\underline{Z}_1 \cdot \underline{Z}_4\} = Re\{\underline{Z}_2 \cdot \underline{Z}_3\}$

$\varphi_1 + \varphi_4 = \varphi_2 + \varphi_3$ | $Im\{\quad\} = Im\{\quad\}$

d) $\varphi_{Cx} + \varphi_{R4} \overset{!}{=} \varphi_3 + \varphi_{R2}$ Abgleich nur mit Element

$\varphi_{Cx} = -90°$, $\varphi_{R4} = 0°$, $\varphi_3 = ?$, $\varphi_{R2} = 0°$ gleicher Phase, d.h. C

7.5 induktive u. kapazitive Sensoren

a) Queranker-geber, Tauchankeraufnehmer } Einzelsystem $L = k \frac{1}{x} = k_L \frac{1}{s + \Delta s}$

Differential-Tauchanker... Doppelsystem $L_{1,2} = k_L \frac{1}{s \pm \Delta s}$

b) Plattenkondensator Einzelsystem $C = k_C \frac{1}{x} = k_C \frac{1}{s + s_0}$

Differential ~ Doppelsystem $C_{1,2} = k_C \frac{1}{s \pm \Delta s}$

Messgrößen: Abstand, Schichtdicke

Linearität: $\sim \frac{1}{x}$ → in Halbbrücken Linearität