1. Messabweichungen

1.1 Zufällige Abweichungen

1.1.1 Linearer Mittelwert

$$\overline{x} = \frac{1}{n} \cdot \sum_{i=1}^{n} x_i \qquad x_w = \lim_{i \to \infty} \overline{x}$$

1.1.2 Streuung

$$S^2 = \frac{1}{n} \cdot \sum_{i=1}^{n} (x_i - x_w)^2$$ wenn der wahre Wert x_w bekannt ist

$$S^2 = \frac{1}{n-1} \cdot \sum_{i=1}^{n} (x_i - \overline{x})^2$$ wenn der wahre Wert unbekannt ist, $S^2 = \frac{1}{2}\sum_{i=1}^{2}(x_i - \overline{x})^2$ mit $\overline{x} = \frac{x_1 + x_2}{2}$

1.1.3 Grundaxiom, Energetische Addition

$A_{ges}{}^2 = A_1{}^2 + A_2{}^2$ Wahrscheinlichster Fall

$A_{ges} = A_1 + A_2$ Schlimmster Fall

1.1.4 Vertrauensgrenze

$$\overline{x} = x_w + \frac{s}{\sqrt{n}}$$ allgemein

$$\overline{x} = x_w + t \cdot \frac{s}{\sqrt{n}}$$ Gauß – verteilt, t = Studentfaktor

1.1.5 systematische Fehler

$$y = f(x) \Rightarrow \Delta y = \frac{\delta y}{\delta x} \cdot \Delta x$$ absoluter Fehler

$$y = x^n \Rightarrow \frac{\Delta y}{y} = n \cdot \frac{\Delta x}{x}$$ relativer Fehler

1.1.6 Rechnen mit kleinen Größen (Näherungen)

$$\left.\begin{aligned} &(1+\Delta x)^n \approx 1 + n \cdot \Delta x \\ &e^{\Delta x} \approx 1 + \Delta x \\ &\ln(1+\Delta x) \approx \Delta x \\ &\sin(\Delta x) \approx \Delta x \\ &\tan(\Delta x) \approx \Delta x \end{aligned}\right\}$$ Näherungen für sehr kleine Δx

2. Signale

2.1 Sinusförmige Signale

2.1.1 Augenblicksleistung

$$P(t) = u(t) \cdot i(t)$$

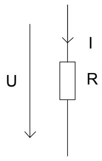
$$\Rightarrow \cos(\alpha) \cdot \cos(\beta) = \frac{1}{2} \cdot \cos(\alpha + \beta) + \frac{1}{2} \cdot \cos(\alpha - \beta)$$

$$\Rightarrow P(t) = \frac{\hat{u} \cdot \hat{i}}{2} \cdot \left[\cos(2\omega t + \varphi_u + \varphi_i) + \cos(\varphi_u - \varphi_i)\right]$$

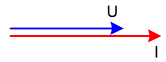
$$\Rightarrow P(t) = \underbrace{U_{eff} \cdot I_{eff} \cdot \cos(2\omega t + \varphi_u + \varphi_i)}_{P_{\sim}(t)} + \underbrace{U_{eff} \cdot I_{eff} \cdot \cos(\varphi_u - \varphi_i)}_{\overline{P(t)}}$$

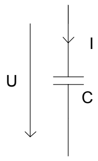
2.1.2 Wirkleistung

$$P_w = \overline{P(t)} = \underbrace{\frac{1}{T}\int_0^T u \cdot i \cdot dt}_{\text{Allgemein}} = \underbrace{U_{eff} \cdot I_{eff} \cdot \cos(\varphi_u - \varphi_i)}_{\text{Speziell}}$$ Mittelwert der Augenblicksleistung

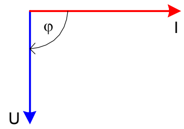


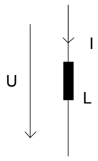
$$U = R \cdot I$$
$$P_w = U_{eff} \cdot I_{eff} \cdot \cos(0°)$$
$$\varphi_u = \varphi_i$$



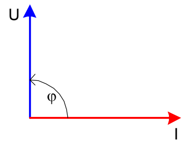


$$U = \frac{1}{C} \cdot \int i(t) \cdot dt$$
$$P_w = U_{eff} \cdot I_{eff} \cdot \cos(-90°) = 0$$
$$\varphi_u = \varphi_i - 90°$$
$$\underline{U} = \underbrace{\frac{1}{j\omega C}}_{X_C} \cdot \underline{I}$$





$$U = L \cdot \frac{di}{dt}$$
$$P_w = U_{eff} \cdot I_{eff} \cdot \cos(90°) = 0$$
$$\varphi_u = \varphi_i + 90°$$
$$\underline{U} = \underbrace{j\omega L}_{X_L} \cdot \underline{I}$$

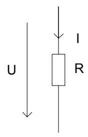


2.1.3 Scheinleistung

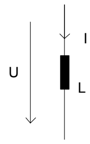
$$P_S = U_{eff} \cdot I_{eff}$$

2.1.4 Blindleistung

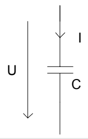
$$P_B = U_{eff} \cdot I_{eff} \cdot \sin(\varphi_u - \varphi_i)$$
$$P_B{}^2 = P_w{}^2 + P_B{}^2 \Rightarrow P_B = \sqrt{P_S{}^2 + P_w{}^2}$$



$$P_B = U_{eff} \cdot I_{eff} \cdot \sin(0°)$$
$$P_B = 0$$



$$P_B = U_{eff} \cdot I_{eff} \cdot \sin(90°)$$
$$P_B = U_{eff} \cdot I_{eff}$$



$$P_B = U_{eff} \cdot I_{eff} \cdot \sin(-90°)$$
$$P_B = -U_{eff} \cdot I_{eff}$$

2.1.5 Signalleistung

$$P = \overline{u^2} = U_{eff}^2$$ Signalleistung allgemein

$$P = \frac{1}{T_0} \int_0^{T_0} \hat{u}^2 \cdot \cos^2(\omega t) \cdot dt \quad \Leftrightarrow \quad P = \frac{1}{2}\hat{u}^2$$ Signalleistung im Zeitbereich

$$P = \frac{1}{2}\hat{u}^2 = \left(\frac{\hat{u}}{\sqrt{2}}\right) \quad \begin{cases} P = \frac{1}{2}\sum(\text{Verlauf})^2 & \text{einseitiges Spektrum} \\ P = \sum(\text{Verlauf})^2 & \text{zweiseitiges Spektrum} \end{cases}$$

2.1.6 Spektrum

$$u = \hat{u}\frac{1}{2 \cdot j}\left(e^{j\omega t} - e^{-j\omega t}\right) = \frac{1}{2} \cdot \hat{u} \cdot \frac{1}{j} \cdot e^{j\omega t} + \frac{1}{2} \cdot \hat{u} \cdot \left(-\frac{1}{j}\right) \cdot e^{j\omega t}$$ zweiseitiges Spektrum

2.2 Nicht sinusförmige Signale

2.2.1 Augenblicksleistung

$$P(t) = u(t) \cdot i(t)$$

2.2.2 Wirkleistung

$$P_w(t) = \overline{P(t)} = \overline{u(t) \cdot i(t)}$$

2.2.3 Signalleistung

$$P_x = U_{eff}^2 = \overline{u^2(t)}$$

2.2.4 Effektivwert

$$U_{eff}^2 = \overline{u}^2 = u^2 = \frac{1}{T}\cdot\int_0^T u(t)^2\,dt$$ RMS-Wert

$$X_{eff}^2 = \frac{1}{T}\int_{t_0}^{T+t_0} x^2 dt$$ allgemein

2.2.5 Linearer Mittelwert (Gleichanteil)

$$\overline{u(t)} = \frac{1}{T}\cdot\int_0^T u(t)\cdot dt$$

2.2.6 Gleichrichtwert

$$\left|\overline{u(t)}\right| = \frac{1}{T}\int_0^T |u(t)|\,dt$$

2.2.7 Formfaktor

$$F = \frac{U_{eff}}{\left|\overline{u(t)}\right|}$$

$$\Leftrightarrow \text{Formfakor} = \frac{\text{Effektivwert}}{\text{Gleichrichtwert}}$$

$$F_{sinus} = \frac{\pi}{2\sqrt{2}}$$

2.2.8 Scheitelfaktor

$$S = \frac{\hat{u}}{U_{eff}}$$

$$\Leftrightarrow \text{Scheitelfaktor} = \frac{\text{Scheitelwert}}{\text{Effektivwert}}$$

$$S_{sinus} = \sqrt{2} \quad ; \qquad S_{dreieck} = \sqrt{3}$$

2.2.9 einseitige Fourierreihe $f \geq 0$

$$f(t) = \frac{a_0}{2} + \sum_{n=1}^{\infty}\left[a_n\cdot\cos(2\pi n f_0 t) + b_n\cdot\sin(2\pi n f_0 t)\right]$$

$$f_0 = \frac{1}{T_0}$$ bei periodischen Signalen

$$\frac{a_0}{2} = \frac{1}{T}\cdot\int_0^T f(t)\,dt$$

$$\frac{a_n}{2} = \frac{1}{T}\cdot\int_0^T f(t)\cdot\cos(2\pi n f_0 t)\,dt$$

$$\frac{b_n}{2} = \frac{1}{T}\cdot\int_0^T f(t)\cdot\sin(2\pi n f_0 t)\,dt$$

2.2.10 beidseitige Fourierreihe $-\infty \leq f \leq +\infty$

$$f(t) = \frac{a_0}{2} + \sum_{n=-\infty}^{\infty}\left[\frac{a_n}{2}\cdot\cos(2\pi n f_0 t) + \frac{b_n}{2}\cdot\sin(2\pi n f_0 t)\right]$$! ohne n = 0 !

2.2.11 komplexe Fourierreihe

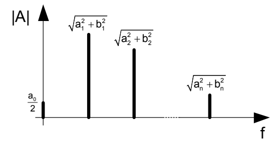
$$f(t) = \sum_{n=-\infty}^{+\infty} c_n\cdot e^{j2\pi f_0 n t}$$

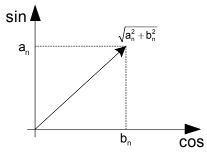
$$c_n = \frac{1}{T}\cdot\int_0^T f(t)\cdot e^{-j2\pi f_0 t}\,dt$$

$$\mathrm{Re}\{c_n\} = \frac{a_n}{2} = \frac{1}{T}\cdot\int_0^T f(t)\cdot\cos(2\pi n f_0 t)\,dt$$

$$\mathrm{Im}\{c_n\} = -j\cdot\frac{b_n}{2} = \frac{1}{T}\cdot\int_0^T f(t)\cdot\sin(2\pi n f_0 t)\,dt$$

2.2.12 Amlitudenspektrum

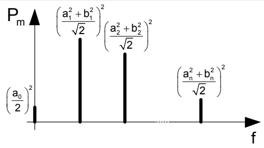




$$P = \overline{f^2(t)}$$

Einseitiges Amplitudenspektrum mit Fourierkoeffizienten

2.2.13 Leistungsspektrum



$$P_{ges} = \text{Linie}_0^2 + \frac{1}{2}\sum_{i=1}^{n}(\text{Linie}_i)^2$$

Einseitiges Leistungsspektrum mit Fourierkoeffizienten

2.2.14 Klirrfaktor

$$k^2 = \frac{\sum_{n=2}^{n} U_{n\,eff}^2}{\sum_{n=1}^{n} U_{n\,eff}^2} \Leftrightarrow \text{Klirrfaktor} = \frac{\text{Störleistung}}{\text{Gesamtleistung}}$$

2.2.15 Welligkeit

$$w^2 = \frac{\sum_{n=2}^{n} U_{n\,eff}^2}{U_{1\,eff}^2} \Leftrightarrow \text{Welligkeit} = \frac{\text{Störleistung}}{\text{gewollte Signalleistung}}$$

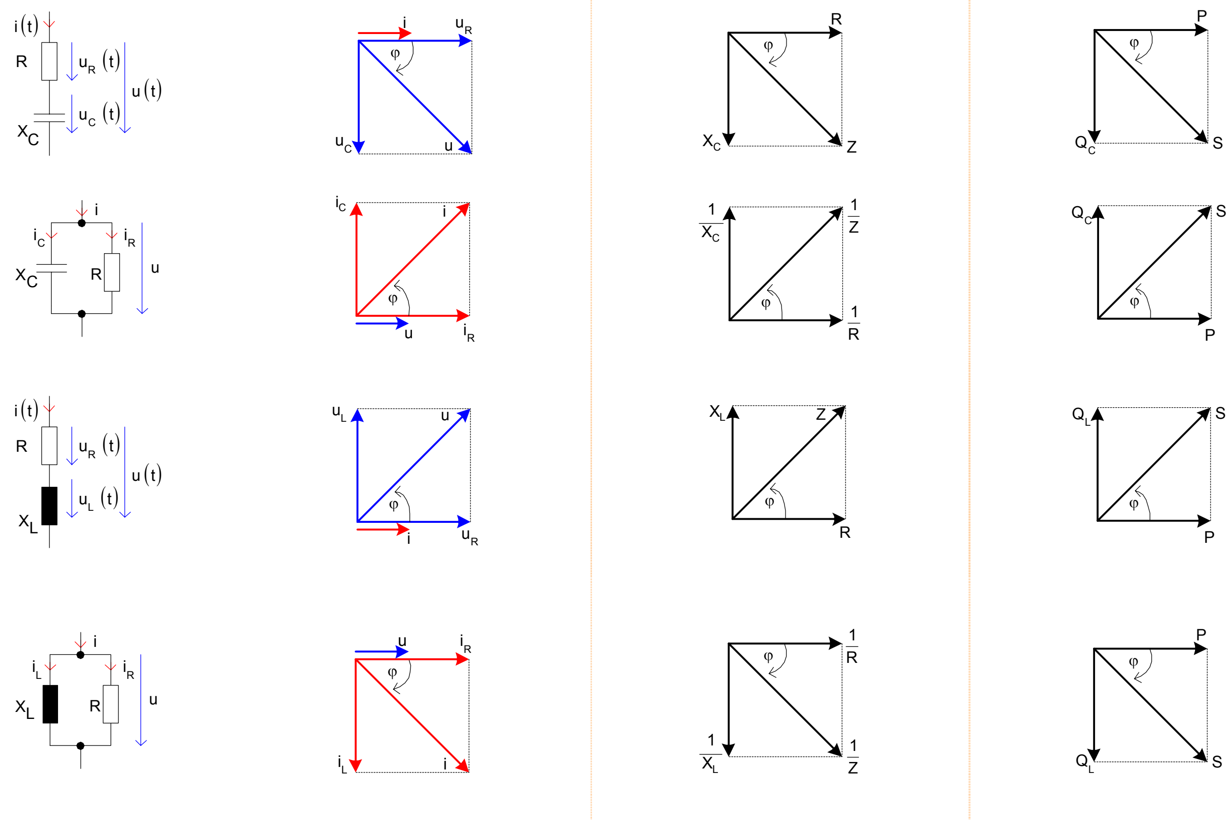
2.2.16 Total Harmonic Distorsion (THD)

$$(\text{THD})^2 = \frac{\text{Effektivwerte aller Oberschwingungen}}{\text{Effektivwert der Grundschwingung}}$$

3. R,L,C,M – Netzwerke

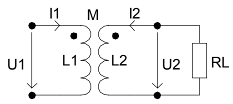
3.1 Widerstände im Wechselstromkreis

3.1.1 Schaltung	Stromstärke und Spannung	Widerstand und Leitwert	Leistung

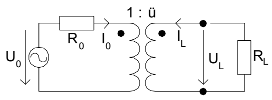


3.2 Der Übertrager

3.2.1 Der ideale Übertrager

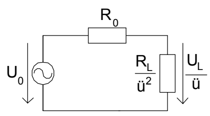


$$\frac{n_1}{n_2} = \frac{u_1}{u_2} = \frac{i_2}{i_1} = \frac{1}{ü}$$

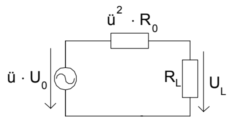


$\Rightarrow$

Ersatzschaltbild für Primärseite

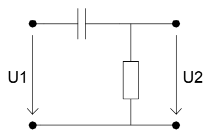


Ersatzschaltbild für Sekundärseite

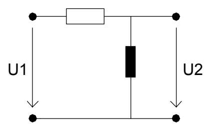


$$R_0 = ü \cdot R_L$$

3.2.2 Hochpass - Übertrager nach Führer



$$\tau = R \cdot C$$



$$\tau = \frac{L}{R}$$

Amplitidengang:

$$\left|A(f)\right| = \frac{U_2}{U_1} = \frac{1}{\sqrt{1+\frac{1}{(\omega\tau)^2}}}$$

Phasengang:

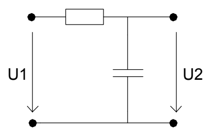
$$\varphi = \arctan\left(\frac{1}{\omega\tau}\right)$$

Übertragungsverhalten:

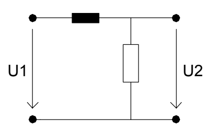
$$A(f) = \frac{j\frac{f}{f_g}}{1+j\frac{f}{f_g}} = \frac{j\omega\tau}{1+j\omega\tau}$$

$$\text{mit} \quad f_g = \frac{1}{2\pi\cdot\tau} = \frac{1}{2\pi\cdot RC} \quad ; \omega\cdot\tau = \frac{f}{f_g}$$

3.2.3 Tiefpass - Übertrager nach Führer



$$\tau = R \cdot C$$



$$\tau = \frac{L}{R}$$

Amplitidengang:

$$\left|A(f)\right| = \frac{U_2}{U_1} = \frac{1}{\sqrt{1+(\omega\tau)^2}}$$

Phasengang:

$$\varphi = -\arctan(\omega\tau)$$

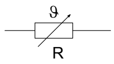
Übertragungsverhalten:

$$A(f) = \frac{1}{1+j\frac{f}{f_g}} = \frac{1}{1+j\omega\tau}$$

$$\text{mit} \quad f_g = \frac{1}{2\pi\cdot\tau} = \frac{1}{2\pi\cdot RC} \quad ; \omega\cdot\tau = \frac{f}{f_g}$$

3.3 Spezifischer Wärmewiderständ

3.3.1 Erwärmter Widerstand



$$R = R_{20} + \Delta R$$

$$R = R_{20}\left(1 + \alpha_{20} \cdot \Delta\vartheta\right)$$

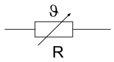
$\alpha_{20} \Rightarrow$ Temperaturbeiwert

$\Delta\vartheta \Rightarrow$ Temperaturänderung

$R_{20} \Rightarrow$ Widerstandswert bei 20°C

$\Delta R \Rightarrow$ Widers tan dsänderung

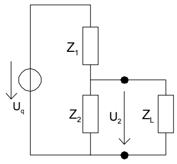
3.3.2 Widerstandszunahme



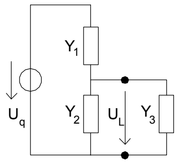
$$\Delta R = R_{20} \cdot \alpha_{20} \cdot \Delta\vartheta$$

3.4 Netzwerke

3.4.1 Spannungsteiler

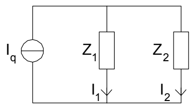


$$\Rightarrow U_2 = \frac{Z_2 Z_L}{Z_1 Z_2 + Z_2 Z_L + Z_1 Z_L} \cdot U_q$$

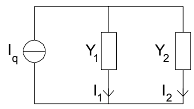


$$\Rightarrow U_2 = \frac{Y_1}{Y_1 + Y_2 + Y_3} \cdot U_q$$

3.4.2 Stromteiler

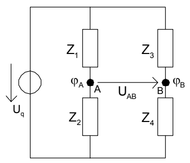


$$\Rightarrow I_2 = \frac{Z_1}{Z_1 + Z_2} \cdot I_q$$

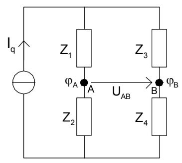


$$\Rightarrow I_2 = \frac{Y_2}{Y_1 + Y_2} \cdot I_q$$

3.4.3 Brückenschaltung

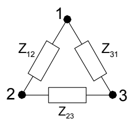
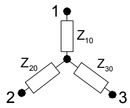


$$\Rightarrow U_{BR} = U_q \cdot \frac{Z_2 Z_3 - Z_1 Z_4}{\left(Z_1 + Z_2\right)\left(Z_3 + Z_4\right)}$$

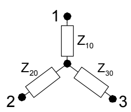
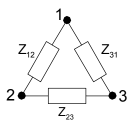


$$\Rightarrow U_{BR} = I_q \cdot \frac{Z_2 Z_3 - Z_1 Z_4}{Z_1 + Z_2 + Z_3 + Z_4}$$

3.4.4 Umwandlung von Schaltungen

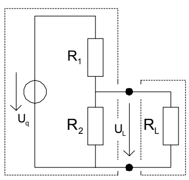
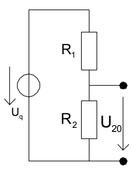
 $\Rightarrow$ 

$$Z_{10} = \frac{Z_{12} \cdot Z_{31}}{\sum Z} \qquad Z_{20} = \frac{Z_{23} \cdot Z_{12}}{\sum Z} \qquad Z_{30} = \frac{Z_{31} \cdot Z_{23}}{\sum Z}$$

 $\Rightarrow$ 

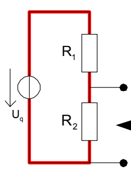
$$Z_{12} = \frac{Z_{10} \cdot Z_{20}}{Z_{30}} + Z_{10} + Z_{20} \qquad Z_{23} = \frac{Z_{20} \cdot Z_{30}}{Z_{10}} + Z_{20} + Z_{30} \qquad Z_{31} = \frac{Z_{30} \cdot Z_{10}}{Z_{20}} + Z_{30} + Z_{10}$$

3.4.5 Ersatzspannungsquelle

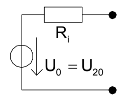
 $\Rightarrow$ 

Klemmen öffnen

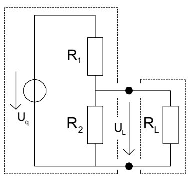
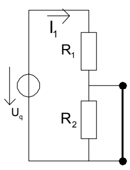
$$U_{20} = \frac{R_2}{R_1 + R_2} \cdot U$$

$\Rightarrow$ 

$$R_i = R_1 \parallel R_2$$

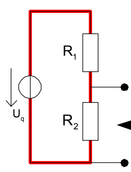
$\Rightarrow$ 

3.4.6 Ersatzstromquelle

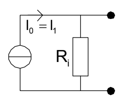
 $\Rightarrow$ 

Klemmen Kurzschließen

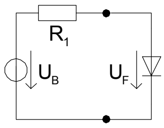
$$I_1 = \frac{U}{R_1}$$

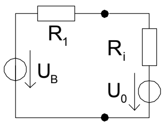
$\Rightarrow$ 

$$R_i = R_1 \parallel R_2$$

$\Rightarrow$ 

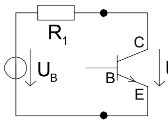
3.4.7 Nichtlineare Netze

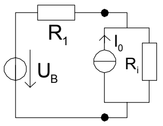


$\Rightarrow$


$$R_i = \frac{\Delta U}{\Delta I}$$

Lösbar nur in Zusammenhang mit Kennlinien



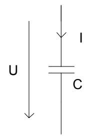
$\Rightarrow$


$$R_i = \frac{\Delta U}{\Delta I}$$

Lösbar nur in Zusammenhang mit Kennlinien

3.5 Energie

3.5.1 Energieinhalt des elektrischen Feldes



Ladung

$$Q = U \cdot C$$

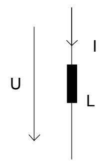
Energie

$$W = \frac{1}{2} \cdot U \cdot Q = \frac{1}{2} \cdot C \cdot U^2 \qquad ;[W] = \frac{As}{V} \cdot V^2 = VAs$$

Mathematische Herleitung

Aus:	$dw = u \cdot i \cdot dt$
folgt mit:	$i = \frac{dq}{dt}$ und $dq = C \cdot du$
das Differential:	$dw = C \cdot u \cdot du$
Durch Integrieren	$\int_0^W dw = \int_0^U u \cdot du$
erhält man:	$W = \frac{1}{2} \cdot C \cdot U^2$

3.5.1 Energieinhalt des magnetischen Feldes



Ladung

$$N \cdot \Phi = L \cdot I$$

Energie

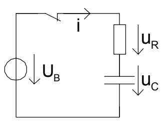
$$W = \frac{1}{2} \cdot I \cdot \Phi \cdot N = \frac{1}{2} \cdot L \cdot I^2 \qquad ;[W] = \frac{As}{V} \cdot V^2 = VAs$$

Mathematische Herleitung

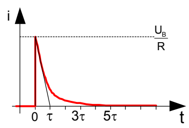
Aus:	$dw = u \cdot i \cdot dt$
folgt mit:	$u = L\frac{di}{dt}$
das Differential:	$dw = L \cdot i \cdot di$
Durch Integrieren	$\int_0^W dw = L\int_0^I i \cdot di$
erhält man:	$W = \frac{1}{2} \cdot L \cdot I^2$

3.6 Schaltvorgänge

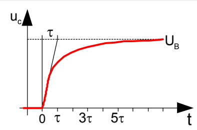
3.6.1 Schaltvorgänge bei Kondensatoren



$$i = \frac{U_B}{R} \cdot e^{-\frac{t}{\tau}} \Rightarrow$$

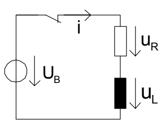


$$u_C = U_B \cdot \left(1 - e^{-\frac{t}{\tau}}\right) \Rightarrow$$

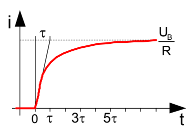


$\tau = RC$

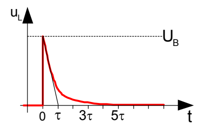
3.6.2 Schaltvorgänge bei Spulen



$$i = \frac{U_B}{R} \cdot \left(1 - e^{-\frac{t}{\tau}}\right) \Rightarrow$$



$$u_L = U_B \cdot e^{-\frac{t}{\tau}} \Rightarrow$$



$\tau = \frac{L}{R}$

3.7 Messwerke

3.7.1 Drehspulmesswerk

Wichtige Eigenschaften:

- Das Messwerk ist nur für Gleichstrom geeignet
- Es misst stets den arithmetischen Mittelwert (Gleichwert)

Vorteile sind:

- ✓ Die sehr hohe Empfindlichkeit
- ✓ Der geringer Eigenverbrauch
- ✓ Eine lineare Skala
- ✓ Der geringer Fremdfeldeinfluss

Durch Vorschalten von Gleichrichtern oder Thermoumformern sind auch Wechselströme messbar.

3.7.2 Dreheisenmesswerk

Wichtige Eigenschaften:

- Es können Gleich- und Wechselströme gemessen werden
- Sie messen bis ca. 300 Hz unabhängig von der Kurvenform den Effektivwert (TRMS)

Vorteile sind:

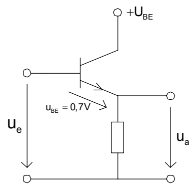
- ✓ Der robuste Aufbau
- ✓ Eignung für Gleich- und Wechselstrom (Effektivwert)
- ✓ Direkter Anschluss an Messwandler möglich

Nachteil ist der hohe Eigenverbrauch von bis zu 5VA, sie eignen sich daher nicht zum Messen kleiner Werte.

4. Verstärker

4.1 Transistor - Grundverstärkerschaltungen

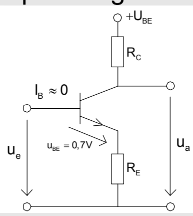
4.1.1 Stromverstärker



Emiterfolger

$$\Delta u_e \approx \Delta u_a$$

4.1.2 Spannungsverstärker



Kollektorfolger

$$v = \frac{\Delta u_a}{\Delta u_e} = -\frac{R_C}{R_E}$$

4.1.3 Großsignalverhalten

$$I_B = I_0 \cdot e^{\frac{U_B}{U_T}} \quad \text{mit } U_T \approx 27\text{mV}$$

$$I_C = \beta \cdot I_B$$

$$I_E = I_B + I_C$$

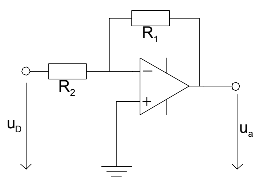
4.1.4 Kleinsignalverhalten

$$\Delta I_B = \underbrace{I_0 \cdot e^{\frac{U_B}{U_T}}}_{I_B} \cdot \frac{1}{U_T} \cdot \Delta U_B = \frac{I_B}{U_T} \cdot \Delta I_B$$

$$\Delta I_C = \beta \cdot \Delta I_B$$

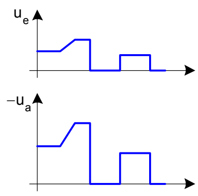
4.2 Operationsvertärker

4.2.1 Invertierer

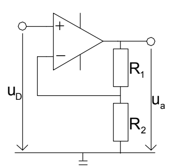


$$u_a = -u_e \cdot \frac{R_1}{R_2}$$

$$v = \frac{u_a}{u_e} = -\frac{R_1}{R_2}$$

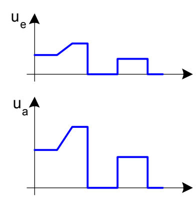


4.2.2 Nichtinvertierer

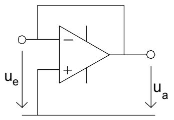


$$u_a = u_e\left(1 + \frac{R_1}{R_2}\right)$$

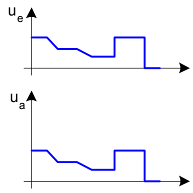
$$v = \frac{u_a}{u_e} = 1 + \frac{R_1}{R_2}$$



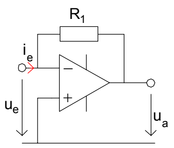
4.2.3 Impedanzwandler



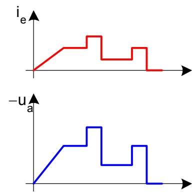
$$u_a = u_e$$



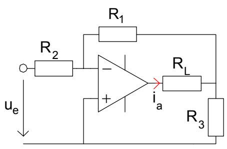
4.2.4 Strom- Spannungswandler



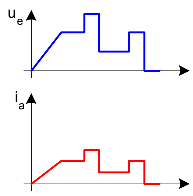
$$u_a = -i_e \cdot R_2$$



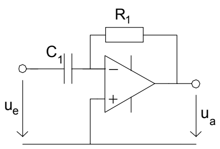
4.2.5 Spannungs- Stromwandler



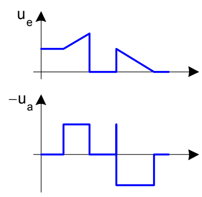
$$i_a = \frac{u_e}{R_2} \cdot \left(1 + \frac{R_1}{R_3}\right)$$



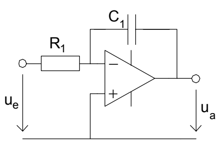
4.2.6 Differenzierer (Hochpass)



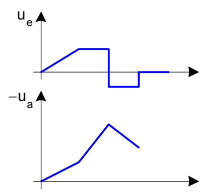
$$u_a = -u_e R_1 \cdot \omega \cdot C_1$$



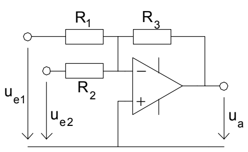
4.2.7 Integrierer (Tiefpass)



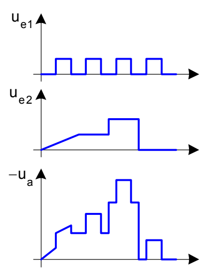
$$u_a = -u_e \frac{1}{R_1 \cdot \omega \cdot C_1}$$



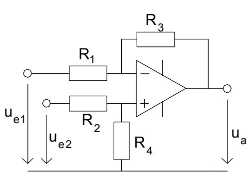
4.2.8 Summierverstärker



$$u_a = -R_3 \left(\frac{u_{e1}}{R_1} + \frac{u_{e2}}{R_2}\right)$$



4.2.9 Differenzverstärker

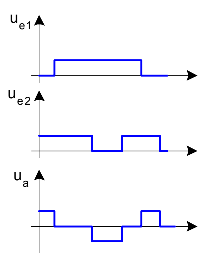


$$u_a = \frac{R_3}{R_1}\left(u_{e2} - u_{e1}\right)$$

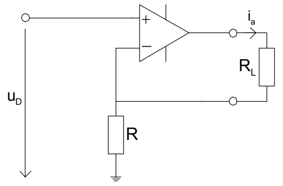
mit

$$R_1 = R_2$$

$$R_3 = R_4$$



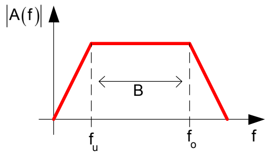
4.2.10 Spannungsgesteuerte Stromquelle



$$i_a = \frac{u_e}{R}$$

4.2.11 Bandbreite

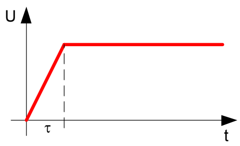
$$B = f_o - f_u$$



4.2.12 Anstiegszeit

$$T_A = \frac{0{,}35}{f_g} \quad \text{von 10\% bis 90\%}$$

$$T_{Ages} = T_{A1}^2 + T_{A2}^2 + T_{A3}^2 + \ldots + T_{An}^2$$



$$T_{Aein} = 0{,}8 \cdot \tau$$

$$T_{AVerst.} = \frac{1}{3} \cdot T_{Aein}$$

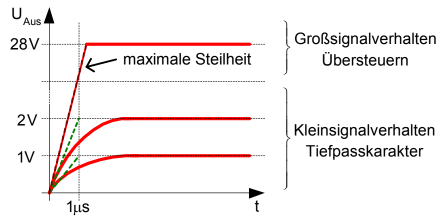
$$B = \frac{0{,}35}{T_{AVerst.}}$$

4.2.13 Großsignalverhalten – Slewrate

$$SR = u_{max}\left(\frac{du_a}{dt}\right)$$ maximale Steigung

SR – Slewrate

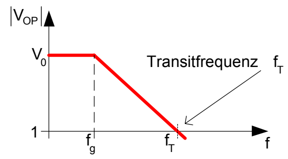
$$u_{ss} \cdot f_{max} = \frac{SR}{\pi}$$ bei sinusförmiger Ansteuerung



4.2.14 Kleinsignalverhalten – Grenzfrequenz

$$V_{OP} = \frac{V_0}{1 + j\frac{f}{f_g}}$$

Tiefpass erster Ordnung

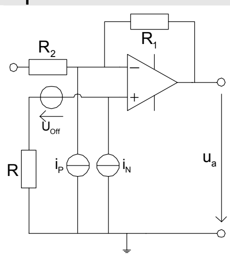


4.2.15 Transitfrequenz

$$B \cdot V = f_T$$

B – Bandbreite
V – Verstärkung

4.2.16 Operationsverstärker mit Ruheströmen und Offsetspannungen

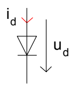


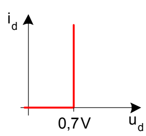
$$u_a = -\frac{R_1}{R_2} \cdot u_e + \left(1 + \frac{R_1}{R_2}\right) \cdot U_{off} + R_1 \cdot i_N - R\left(1 + \frac{R_1}{R_2}\right) \cdot i_P$$

5. Halbleiter

5.1 Diode

5.1.1 Wirkleistung





$$u_d = \begin{cases} 0{,}7V & \text{bei } i_d > 0 \\ \text{egal} & \text{bei } i_d = 0 \end{cases}$$

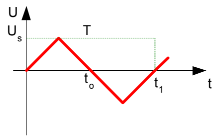
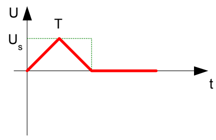
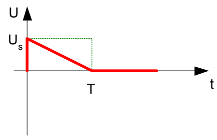
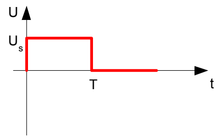
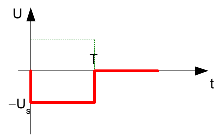
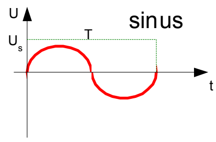
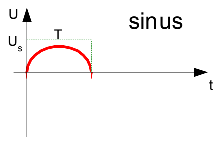
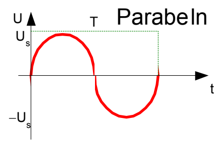
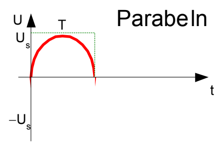
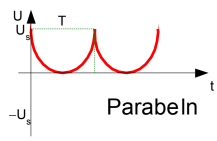
$$P_W = \overline{P(t)} = \overline{i_d(t) \cdot u_d(t)}$$

$\overline{P(t)}$ ist **der Mittelwert** , nicht der Effektivwert

5. Halbleiter

6. Vereinfachungen

6.1 Signalwerte

6.1.1 Signalform	Mittelwert	Gleichrichtwert	Effektivwert	Fourierreihe
	$\bar{U}=\frac{1}{T}\cdot\int U(t)dt$	$\lvert U\rvert=\frac{1}{T}\cdot\int\lvert U(t)\rvert dt$	$U_{eff}^2=\frac{1}{T}\cdot\int U(t)^2\,dt$	Achtung nur für periodische Signale!
	$\bar{U}=0$	$\lvert U\rvert=\frac{U_s}{2}$	$U_{eff}^2=\frac{U_s^2}{3}$	$f(t)=\frac{8}{\pi^2}\cdot U_s\left(\frac{1}{1^2}\sin(t)-\frac{1}{3^2}\sin(3t)+\frac{1}{5^2}\sin(5t)\mp\cdots\right)$
	$\bar{U}=\frac{U_s}{2}$	$\lvert U\rvert=\frac{U_s}{2}$	$U_{eff}^2=\frac{U_s^2}{3}$	$f(t)=\frac{U_s}{2}-\frac{4U_s}{\pi^2}\left(\frac{1}{1^2}\cos(t)+\frac{1}{3^2}\cos(3t)+\frac{1}{5^2}\sin(5t)+\cdots\right)$
	$\bar{U}=\frac{U_s}{2}$	$\lvert U\rvert=\frac{U_s}{2}$	$U_{eff}^2=\frac{U_s^2}{3}$	$f(t)=\frac{U_s}{2}+\frac{U_s}{\pi}\left(\sin(t)+\frac{1}{2}\sin(2t)+\frac{1}{3}\sin(3t)+\cdots\right)$
	$\bar{U}=U_s$	$\lvert U\rvert=U_s$	$U_{eff}^2=U_s^2$	für periodischen Rechteckimpuls: $f(t)=\frac{U_s}{2}+\frac{2U_s}{\pi}\left(\sin(t)+\frac{1}{3}\sin(3t)+\frac{1}{5}\sin(5t)+\cdots\right)$
	$\bar{U}=-U_s$	$\lvert U\rvert=U_s$	$U_{eff}^2=U_s^2$	
	$\bar{U}=0$	$\lvert U\rvert=\frac{2}{\pi}\cdot U_s$	$U_{eff}^2=\frac{1}{2}\cdot U_s^2$	
	$\bar{U}=\frac{2}{\pi}\cdot U_s$	$\lvert U\rvert=\frac{2}{\pi}\cdot U_s$	$U_{eff}^2=\frac{1}{2}\cdot U_s^2$	$f(t)=\frac{4U_s}{\pi}\left(\frac{1}{2}-\frac{1}{1\cdot 3}\cos(2t)-\frac{1}{3\cdot 5}\cos(4t)-\frac{1}{5\cdot 7}\cos(6t)-\cdots\right)$
	$\bar{U}=\frac{2}{3}\cdot U_s$	$\lvert U\rvert=0$	$U_{eff}^2=\frac{8}{15}\cdot U_s^2$	$f(t)=\frac{32}{\pi^3}\cdot U_s\left(\frac{1}{1^2}\sin(t)+\frac{1}{3^3}\sin(3t)+\frac{1}{5^3}\sin(5t)+\cdots\right)$
	$\bar{U}=\frac{2}{3}\cdot U_s$	$\lvert U\rvert=\frac{2}{3}\cdot U_s$	$U_{eff}^2=\frac{8}{15}\cdot U_s^2$	
	$\bar{U}=\frac{1}{3}\cdot U_s$	$\lvert U\rvert=\frac{1}{3}\cdot U_s$	$U_{eff}^2=\frac{1}{15}\cdot U_s^2$	$f(t)=\frac{U_s}{3}+\frac{4U_s}{\pi^2}\left(\cos(t)+\frac{1}{2^2}\cos(2t)+\frac{1}{3^2}\cos(3t)+\cdots\right)$

7. Mathematische Grundlagen

7.1 Goniometrische Beziehungen (Additionstheoreme)

7.1.1 Summen und Differenzen

$$\sin(\alpha \pm \beta) = \sin(\alpha)\cdot\cos(\beta) \pm \cos(\alpha)\cdot\sin(\beta)$$

$$\cos(\alpha \pm \beta) = \cos(\alpha)\cdot\cos(\beta) \mp \sin(\alpha)\cdot\sin(\beta)$$

7.1.2 Doppelte, halbe Winkel

$$\sin(2\alpha) = 2\cdot\sin(\alpha)\cdot\cos(\alpha)$$

$$\cos(2\alpha) = \cos^2(\alpha) - \sin^2(\alpha)$$

7.1.3 Terme von Vielfachen eines Winkels

$$\sin(3\alpha) = 3\cdot\sin(\alpha) - 4\cdot\sin^3(\alpha)$$

$$\sin(4\alpha) = 8\cdot\sin(\alpha)\cdot\cos^3(\alpha) - 4\cdot\sin(\alpha)\cdot\cos(\alpha)$$

$$\cos(3\alpha) = 4\cdot\cos^3(\alpha) - 3\cdot\cos(\alpha)$$

$$\cos(4\alpha) = 8\cdot\cos^4(\alpha) - 8\cdot\cos^2(\alpha) + 1$$

7.1.4 Summen und Differenzen von Trigonometrischen Termen

$$\sin(\alpha) + \sin(\beta) = 2\cdot\sin\left(\frac{\alpha+\beta}{2}\right)\cdot\cos\left(\frac{\alpha-\beta}{2}\right)$$

$$\sin(\alpha) - \sin(\beta) = 2\cdot\cos\left(\frac{\alpha+\beta}{2}\right)\cdot\sin\left(\frac{\alpha-\beta}{2}\right)$$

$$\cos(\alpha) + \cos(\beta) = 2\cdot\cos\left(\frac{\alpha+\beta}{2}\right)\cdot\cos\left(\frac{\alpha-\beta}{2}\right)$$

$$\cos(\alpha) - \cos(\beta) = -2\cdot\sin\left(\frac{\alpha+\beta}{2}\right)\cdot\sin\left(\frac{\alpha-\beta}{2}\right)$$

$$\cos(\alpha) \pm \sin(\alpha) = \sqrt{2}\cdot\sin(45° \pm \alpha) = \sqrt{2}\cdot\cos(45° \mp \alpha)$$

7.1.5 Produkte von trigonometrischen Termen

$$\sin(\alpha)\cdot\sin(\beta) = \frac{1}{2}\left[\cos(\alpha-\beta) - \cos(\alpha+\beta)\right]$$

$$\cos(\alpha)\cdot\cos(\beta) = \frac{1}{2}\left[\cos(\alpha-\beta) + \cos(\alpha+\beta)\right]$$

$$\sin(\alpha)\cdot\cos(\beta) = \frac{1}{2}\left[\sin(\alpha-\beta) + \sin(\alpha+\beta)\right]$$

7.1.6 Potenzen von trigonometrischen Termen

$$\sin^2(\alpha) = \frac{1}{2} - \frac{1}{2}\cdot\cos(2\alpha)$$

$$\cos^2(\alpha) = \frac{1}{2} + \frac{1}{2}\cdot\cos(2\alpha)$$