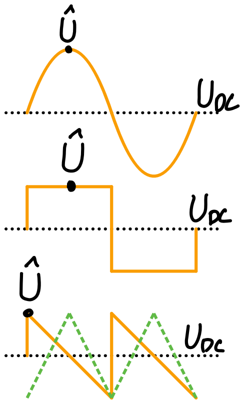
Periodische Signale



Arit. Mittelwert	Gleichrichtwert	Effektivwert
$\bar{U} = U_{DC}$	$\lvert\bar{U}\rvert = \frac{2}{\pi}\hat{U}$	$U_{EFF} = \sqrt{U_{DC}^2 + \frac{\hat{U}^2}{2}}$
$\bar{U} = U_{DC}$	$\lvert\bar{U}\rvert = \frac{2}{\pi}\hat{U}$	$U_{EFF} = \sqrt{U_{DC}^2 + \hat{U}^2}$
$\bar{U} = U_{DC}$	$\lvert\bar{U}\rvert = \frac{\hat{U}}{2}$ *no U_{DC}	$U_{EFF} = \sqrt{U_{DC}^2 + \frac{\hat{U}^2}{3}}$

else

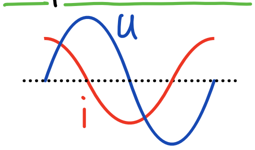
Bei allgemeinen Verläufen steigungen sind nicht fix, sondern von T abhängig

$$\bar{U} = \frac{1}{T}\int_{t_1}^{t_1+T} u(t)\,dt$$

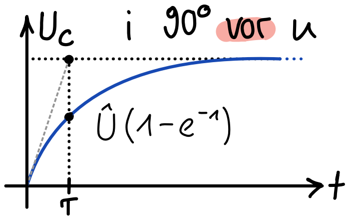
$$\lvert\bar{U}\rvert = \frac{1}{T}\int_{t_1}^{t_1+T} \lvert u(t)\rvert\,dt$$

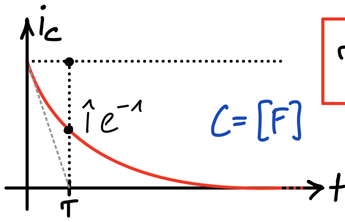
$$U = U_{rms} = \sqrt{\frac{1}{T}\int_{t_1}^{t_1+T} u(t)^2\,dt}$$

Kapazität



i 90° vor u





$C = [F]$

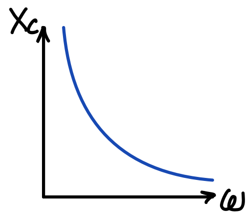
$$\tau = RC$$

$$Z_C = \frac{1}{\omega C j}$$

$$i = C\frac{du}{dt}$$

$$u_C(t) = u_C(\infty) + (u_C(0) - u_C(\infty))\,e^{-\frac{t}{\tau}}$$

$$i_C = \frac{u_C(\infty) - u_C(0)}{R}\,e^{-\frac{t}{\tau}}$$

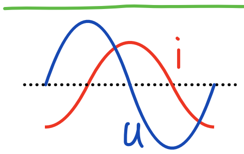


$$u = \hat{U}\,\sin(\omega t + \varphi_u)$$

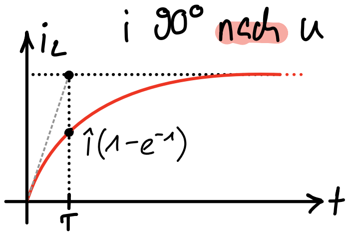
$$\varphi_i = \varphi_u + \frac{\pi}{2}$$

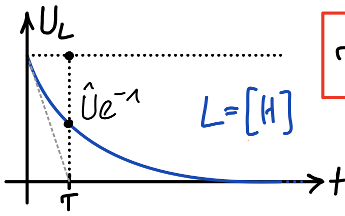
$$\Rightarrow u_C(0+) = u_C(0-)$$

Induktivität



i 90° nach u





$L = [H]$

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

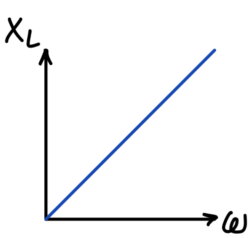
$$Z_L = \omega L j$$

$$u = (-)L\cdot\frac{di}{dt}$$

(−) nicht sicher

$$i_L(t) = i_L(\infty) + (i_L(0) - i_L(\infty))\,e^{-\frac{t}{\tau}}$$

$$u_L = (i_L(\infty) - i_L(0))R\,e^{-\frac{t}{\tau}}$$



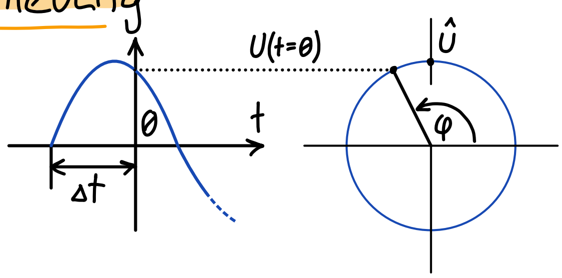
$$i = \hat{I}\,\sin(\omega t + \varphi_i)$$

$$\varphi_u = \varphi_i + \frac{\pi}{2}$$

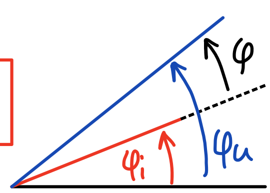
$$\Rightarrow i_L(0+) = i_L(0-)$$

Phasenverschiebung

$$\varphi_{u/i} = \omega\cdot\Delta t$$



$$\varphi = \varphi_u - \varphi_i$$

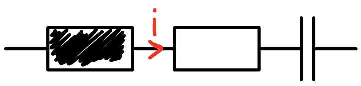


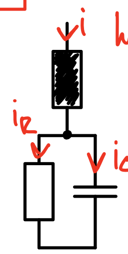
Ausgleichvorgang zweiter Ordnung

$$\boxed{U_q = \frac{1}{\omega_0^2}\frac{d^2u_c}{dt^2} + \frac{2\alpha}{\omega_0^2}\frac{du_c}{dt} + u_c}$$

$$\boxed{u_L = L\cdot\frac{di}{dt} \Rightarrow i = C\cdot\frac{du_c}{dt} \Rightarrow u_L = L\cdot C\cdot\frac{d^2u_c}{dt^2}}$$

→ charakteristische Gleichung





Wichtig Strom i nicht i_C oder i_R, sondern Summe

$$\left[\, i = i_R + i_C = \frac{U_c}{R} + C\cdot\frac{du_c}{dt} \,\right]$$

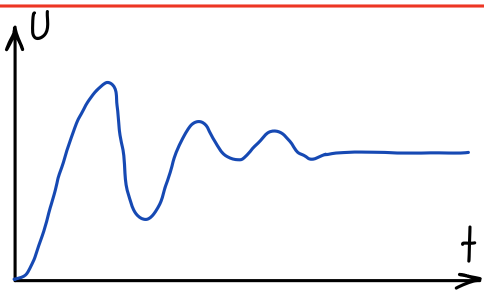
1) $K_3 \rightarrow u_c(t\rightarrow\infty)$ 2) $K_1 \rightarrow u_c(t=0)$ 3) $K_2 \rightarrow \frac{du_c}{dt}(t=0)$

Unterdämpfung $(\alpha^2 - \omega_0^2 < 0)$

$$\boxed{u_c = e^{-\alpha t}\left(K_1\cdot\cos(\omega t) + K_2\cdot\sin(\omega t)\right) + K_3} \qquad \boxed{\omega = \sqrt{\omega_0^2 - \alpha^2}}$$

$$\boxed{\frac{du_c(t)}{dt} = -\alpha e^{-\alpha t}\left(K_1\cos(\omega t) + K_2\sin(\omega t)\right) + e^{-\alpha t}\left(-K_1\omega\sin(\omega t) + K_2\omega\cos(\omega t)\right)}$$

$$\boxed{\dot{u}_c(0) = -\alpha K_1 + K_2\,\omega} = \frac{i}{C}$$

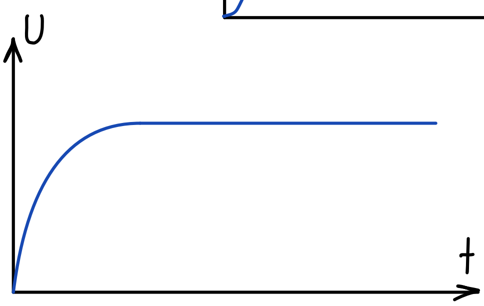


kritische Dämpfung $(\alpha^2 - \omega_0^2 = 0)$

$$\boxed{u_c(t) = e^{-\alpha t}\left(K_1 + K_2 t\right) + K_3}$$

$$\boxed{\frac{du_c(t)}{dt} = e^{-\alpha t}\left(-\alpha K_1 + K_2(1-\alpha t)\right)}$$

$$\boxed{\dot{u}_c(0) = -\alpha K_1 + K_2}$$

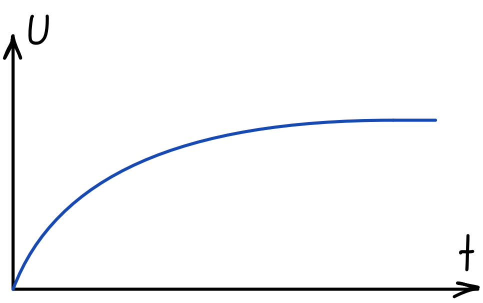


Überdampfung $(\alpha^2 - \omega_0^2 > 0)$

$$\boxed{u_c(t) = e^{-\alpha t}\left(K_1 e^{\delta t} + K_2 e^{-\delta t}\right) + K_3} \qquad \boxed{\delta = \sqrt{\alpha^2 - \omega_0^2}}$$

$$\boxed{\dot{u}_c(t) = e^{-\alpha t}\left(K_1(\delta - \alpha)e^{\delta t} - K_2(\alpha + \delta)e^{-\delta t}\right)}$$

$$\boxed{\dot{u}_c(0) = K_1(\delta - \alpha) - K_2(\alpha + \delta)}$$



$(D = \varepsilon \cdot E)$ $(\varepsilon = \varepsilon_r \cdot \varepsilon_0)$

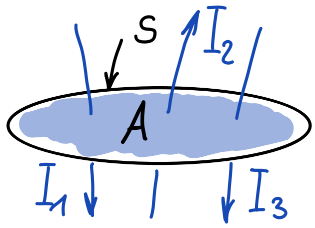
Magnetisches Feld

Durchflutungsgesetz Θ

Gibt eingeschlossenen Strom an.

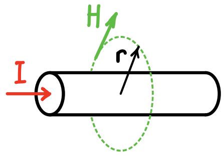
$$\boxed{\Theta = \int_C \vec{H}\, d\vec{s} = I_1 - I_2 + I_3}$$

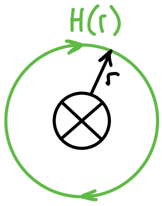
durch Umfang ersetzen



Gerader Leiter

$$\boxed{H(r) = \frac{I}{2\pi r}} \quad \left[\frac{A}{m}\right]$$





Sehr lange Spule

$$\boxed{H = \frac{I \cdot N}{l} = \frac{U_m}{l}}$$

(Länge viel grösser als Durchmesser)

Magnetischer Fluss ϕ

$$\boxed{\phi = \int \vec{B}\, d\vec{A}} \quad [Wb = Vs] \rightarrow \boxed{B = \frac{\phi}{A}}$$

$\phi = B \cdot A$

Magnetische Flussdichte B

$$\boxed{\vec{B} = \mu \cdot \vec{H}} \quad \left[\frac{As}{m^2}\right] \quad \boxed{\mu = \mu_r \cdot \mu_0}$$

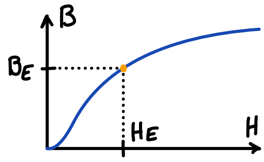
$\rightarrow \mu_0 = 4\pi\, 10^{-7}\ Vs/Am$ $\rightarrow \mu_{rL} = 1$

Berechnung magnetischer Kreise

Typ Synthese

Ges: Θ, I

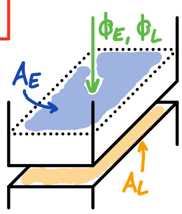
Geg: $B_L, A_E, l_E, A_L, l_L, N$



$$\boxed{\Theta = V_{mL} + V_{mE1} + \cdots + V_{mEn}}$$

$$\boxed{V_{mL} = H_L \cdot l_L = \frac{B_L}{\mu_0} l_L}$$

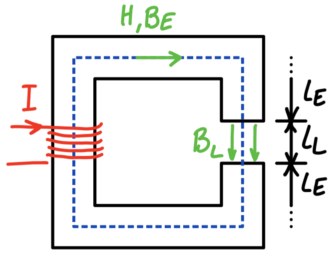
$$\boxed{\begin{gathered}\phi_E = \phi_L \\ B_E A_E = B_L A_L\end{gathered}}$$



Typ Analyse

Ges: B_L

Geg: I, N, A_E, l_E, A_L, l_L



$$\boxed{\Theta = \frac{B_L}{\mu_0} l_L + H_E l_E} \quad \boxed{B_E = \mu_0 \frac{A_L}{A_E\, l_L}(\Theta - H_E l_E)}$$

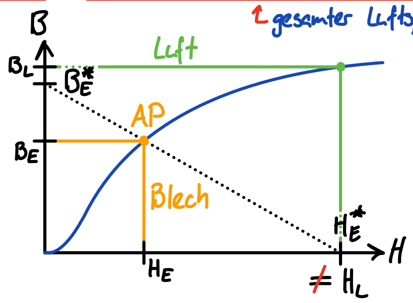
gesamter Luftspalt!

$H_E = 0$

$$\boxed{B_E^* = \mu_0 \frac{A_L}{A_E\, l_L}\Theta}$$

$B_E = 0$

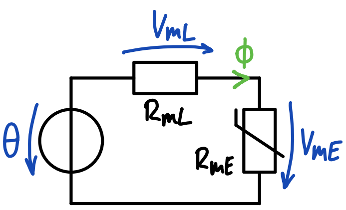
$$\boxed{H_E^* = \frac{\Theta}{l_E}}$$



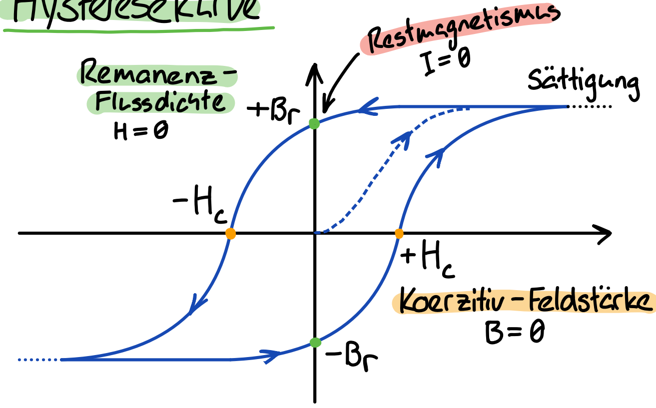
Magnetischer Kreis

$$\boxed{R_m = \frac{l}{\mu A}} \quad \left[\frac{A}{Vs}\right] \quad \boxed{\Sigma\phi = 0}$$

$$\boxed{V_m = R_m \cdot \phi} \quad [A] \quad \boxed{\Sigma V_m = 0}$$



Hysteresekurve



Gesetz von Biot-Savart

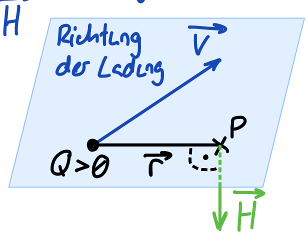
Rechte Handregel!

$$\vec{D}(\vec{r}) = \frac{Q}{4\pi r^2}\frac{\vec{r}}{|\vec{r}|}$$

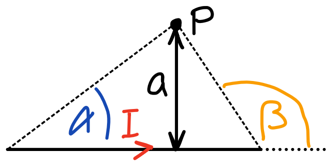
Wenn Ladung bewegt, erzeugt bei Punkt P eine mag. Feldstärke $\vec{H}$

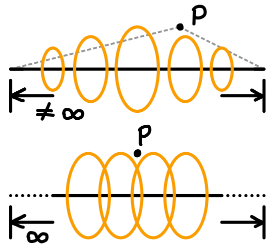
$$\vec{H}(\vec{r}) = \vec{v}\times\vec{D}(\vec{r})$$

$$\vec{H}(\vec{r}) = \frac{I}{4\pi}\int_{Leiter}\frac{d\vec{s}\times\vec{r}}{r^3}$$

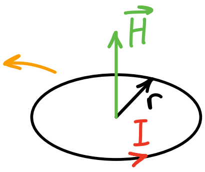


$$H_P = \frac{I}{4\pi a}\left(\cos(\alpha)-\cos(\beta)\right)$$

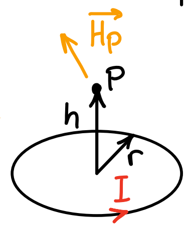




$$H = \frac{I}{2r}$$



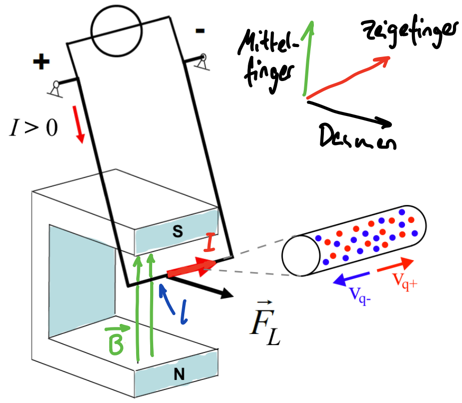
$$|H_P| = \frac{I}{2}\frac{r^2}{(r^2+h^2)^{\frac{3}{2}}}$$



Lorenzkraft

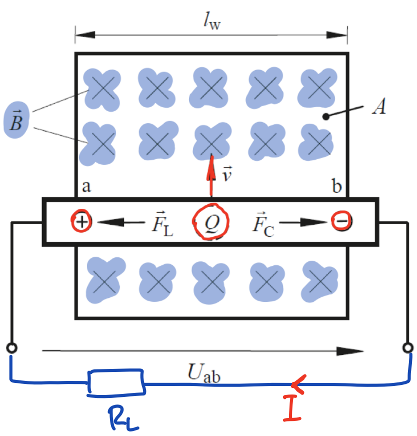
$$\vec{F_L} = \underbrace{Q\,(\vec{v}\times\vec{B})}_{\text{magnetisch}} + \underbrace{Q\cdot\vec{E}}_{\text{elektrische}}$$

$$\vec{F_{Lm}} = I\,(\vec{l}\times\vec{B}) = \underbrace{I\cdot l\cdot B}_{\text{falls homogen}}$$



Bewegungsinduktion

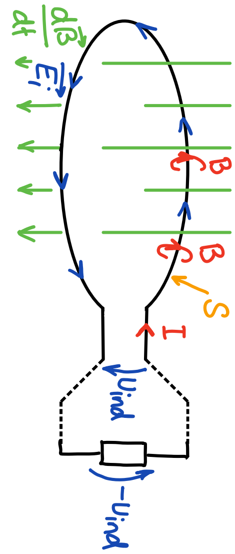
$$U_{AB} = -(\vec{v}\times\vec{B})\cdot\vec{l} = \underbrace{-v\cdot B\cdot L}_{v\perp B\perp l}$$



Ruheinduktion (zeitlich veränderndes Magnetfeld)

$$U_{ind} = -\frac{d\psi}{dt} = -N\cdot\frac{d\phi}{dt}$$

$$U_{ind} = -\oint_S(\vec{E_i}\cdot d\vec{s})$$



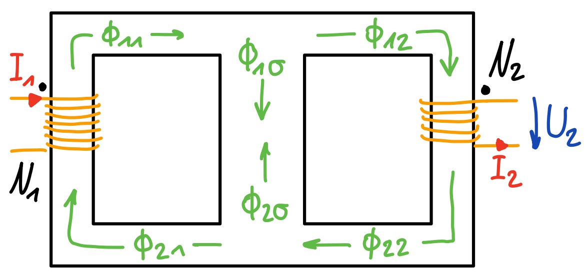
Selbst- und Gegeninduktivität

Ursache $\rightarrow \phi_{21} \leftarrow$ Wirkung

$$k_{21} = \frac{\phi_{21}}{\phi_{22}} \qquad k_{12} = \frac{\phi_{12}}{\phi_{11}} \qquad k = \sqrt{k_{12}\cdot k_{21}}$$

$$L_{21} = N_2\frac{\phi_{21}}{I_2} \qquad L_{12} = N_1\frac{\phi_{12}}{I_1} \qquad L_{21} = L_{12} = k\sqrt{L_1 L_2}$$

$$L_n = \frac{N_n^2}{R_m} \qquad u_{ind} = -L\frac{di(t)}{dt}$$



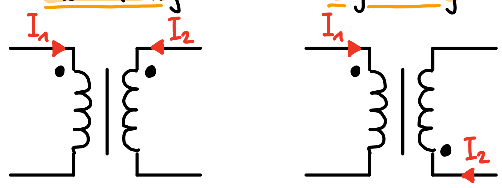
Trafogleichung

$$\boxed{u_1 = N_1 \frac{d\phi_1}{dt} \pm N_1 \frac{d\phi_{21}}{dt} = L_1 \frac{di_1}{dt} \pm L_{21} \frac{di_2}{dt}}$$

$$\boxed{u_2 = N_2 \frac{d\phi_{12}}{dt} \pm N_2 \frac{d\phi_2}{dt} = L_2 \frac{di_2}{dt} \pm L_{12} \frac{di_1}{dt}}$$

↳ = 0 wenn offen

Gleichsinnig   Gegensinnig



+ Gleichsinnig   − Gegensinnig

Energie im Magnetfeld

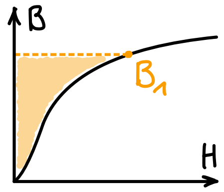
$$\boxed{W_m = L \int_0^I i \, di = \frac{1}{2} L I^2 = \frac{\phi \, \theta}{2}}$$

homogenen Raum

$$\boxed{W_m = \frac{1}{2} B \cdot H \cdot V}$$

Energiedichte

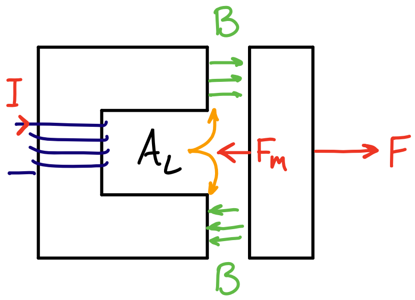
$$\boxed{\omega_m = \frac{dW_m}{dV} = \frac{\mu H^2}{2} = \frac{B^2}{\mu 2}}$$



$$\left(\frac{B^2}{2\mu_0} = \frac{W_m}{V}\right)$$ im Luftspalt

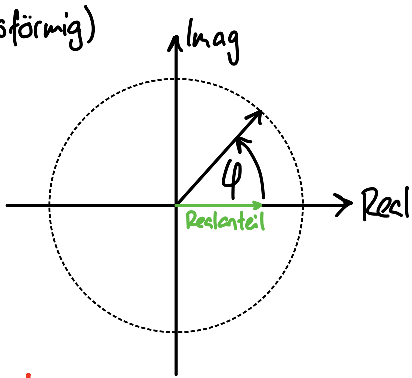
Kraft im Magnetfeld

$$\boxed{F_m = -\frac{dW_m}{dl_L} = -\frac{B^2}{2\mu_0} \cdot A_L}$$

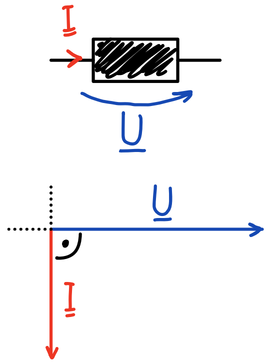


Komplexe Wechselstromrechnung (sinusförmig)

$$\boxed{\underline{U} = U_{EFF} \, e^{j\varphi_U}} \qquad \boxed{\underline{I} = I_{EFF} \, e^{j\varphi_i}}$$

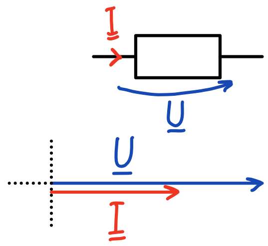


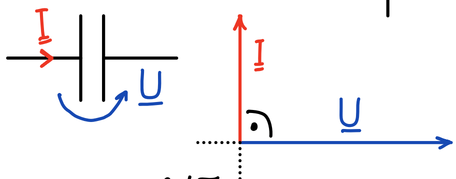
$$u(t) = U_{EFF} \cdot \cos(\varphi_u + \omega t)$$



I eilt $90°/\frac{\pi}{2}$ nach U

Phasoren





I eilt $90°/\frac{\pi}{2}$ vor U

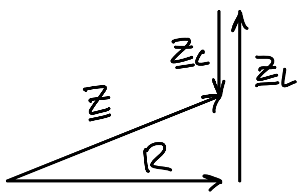
Impedanz

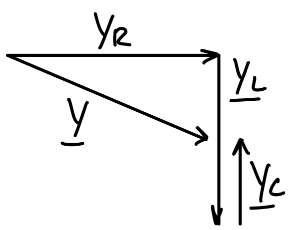
$$\boxed{\underline{Z} = \frac{\underline{U}}{\underline{I}} = Z \angle \varphi}$$

Admittanz

$$\boxed{\underline{Y} = \frac{1}{\underline{Z}} = \frac{\underline{I}}{\underline{U}}}$$

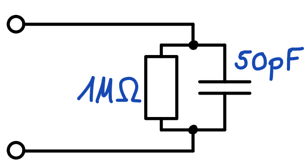
Widerstand	Induktivität	Kapazität
$\underline{Z}_R = R \angle 0° = R$	$\underline{Z}_L = \omega L \angle +90°$	$\underline{Z}_C = \frac{1}{\omega C} \angle -90°$
$\underline{Y}_R = \frac{1}{R \angle 0°} = \frac{1}{R}$	$\underline{Y}_L = \frac{1}{2\pi} \angle -90°$	$\underline{Y}_C = \omega C \angle +90°$



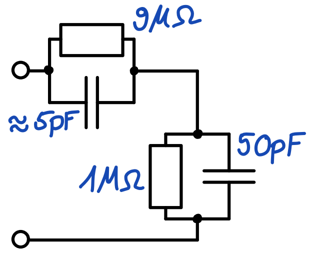


Messtechnik

KO-Sonde 1:1



KO-Sonde 10:1



Messfehler

$$\boxed{F = A - W}$$

$$\boxed{\tilde{f} = \frac{F}{Msp} \cdot 100\%}$$

$|F/A| \ll 1$

$$\boxed{f = \frac{A-W}{W} \cdot 100\% \approx \frac{F}{A} \cdot 100\%}$$

$$\boxed{\sigma \sim \frac{1}{\sqrt{k}}}$$

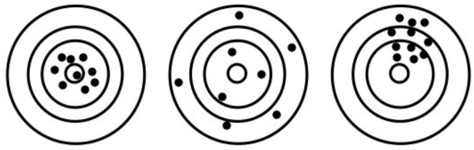
F Absoluter Wert f relativer Wert A Messwert
W Wahrer Wert $\tilde{f}$ normierter Fehler σ Streuung
k # Mittelungen Msp Messspanne

Fehlerausbreitung

$+\,-$ $\boxed{|F_{a+b}| \leq |F_a| + |F_b|}$

$\bullet\,/$ $\boxed{|f_{a\cdot b}| = |f_a| + |f_b|}$

Streuung

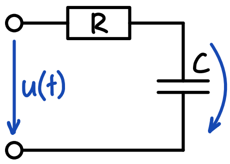


(a) Gute Richtigkeit, gute Präzision, keine Fehler.

(b) Gute Richtigkeit, schlechte Präzision, zufälliger Fehler.

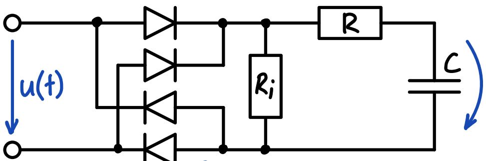
(c) Schlechte Richtigkeit, gute Präzision, systematischer Fehler.

Mittelwert mit MM



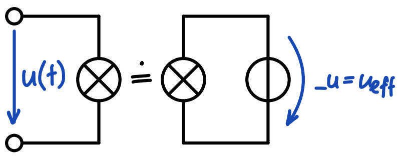
$T = R \cdot C \gg T$

Gleichrichtwert mit MM



$R_i \gg R$ & $T = R \cdot C \gg T$

Effektivwert mit MM



Quartile x_α

$$\boxed{x_\alpha = \begin{cases} \frac{1}{2}(x_{\alpha n} + x_{\alpha \cdot n + 1}) & ① \\ x_k & ② \end{cases}}$$

① falls $\alpha \cdot n$ ganzzahlig

② mit $k = \alpha \cdot n + \frac{1}{2}$ gerundet

Klirrfaktor k

Nur mit AC-Effektivwerten

$$\boxed{k = \sqrt{\frac{U_2^2 + U_3^2 + \cdots}{U_1^2 + U_2^2 + U_3^2 + \cdots}} = \frac{\sqrt{U^2 - U_1^2}}{U}}$$

$$\boxed{k_n = \sqrt{\frac{U_n^2}{U_1^2 + U_2^2 + U_3^2 + \cdots}}}$$

$k^2 = k_1^2 + k_2^2 + \cdots$ ↳ $n \geq 2$

U Effektivwert Gesamtsignal
U_1 Effektivwert Grundschwingung
U_n Effektivwert n-te Oberschwingung

empirische Standardabweichung

$$\boxed{s_x = \sqrt{var} = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (x_i - \bar{x})^2}}$$

Übertragungsfunktion

$$\boxed{\underline{H} = \frac{\underline{U}_{aus}}{\underline{U}_{ein}}}$$

$$\boxed{H_{dB} = 20 \cdot \log_{10}(|\underline{H}|)}$$

$$\boxed{\underline{H} = \underline{H}_1 \cdot \cdots \cdot \underline{H}_n}$$

→ dB & Phasen addieren sich

$$\boxed{\varphi = \angle \underline{H}(j\omega) = \arctan\left(\frac{Im(\underline{H}(j\omega))}{Re(\underline{H}(\omega j))}\right)}$$

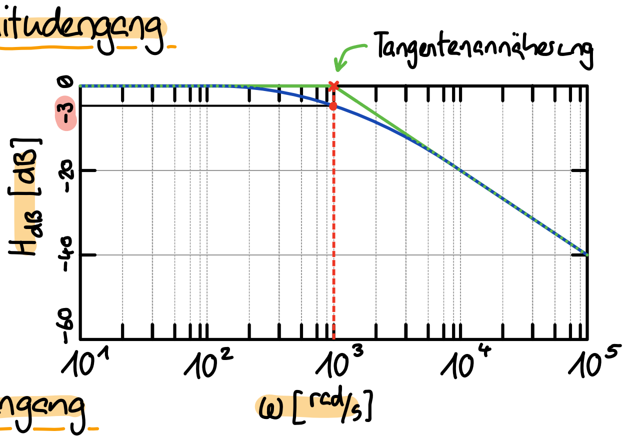
Bei Grenzfrequenz

$$\boxed{|Real(\underline{H})| = |Imag(\underline{H})|}$$

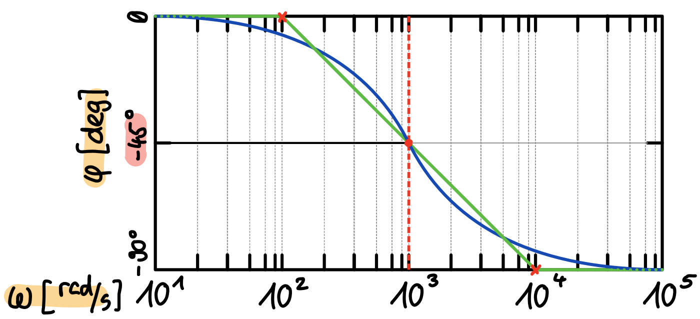
$$\boxed{\varphi = \pm 45°}$$

$$\boxed{|\underline{H}(j\omega_G)| = \frac{1}{\sqrt{2}} \approx -3dB}$$

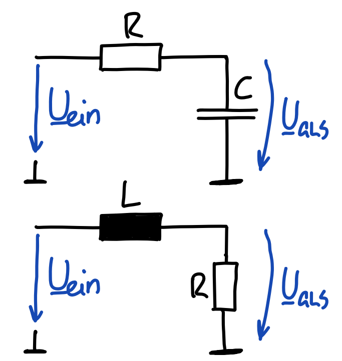
Amplitudengang

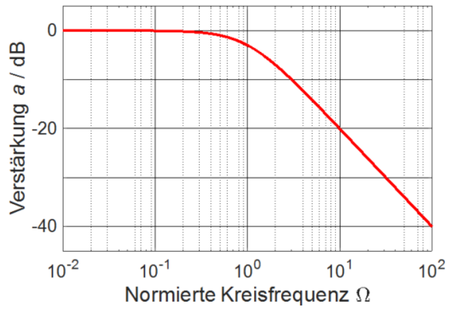


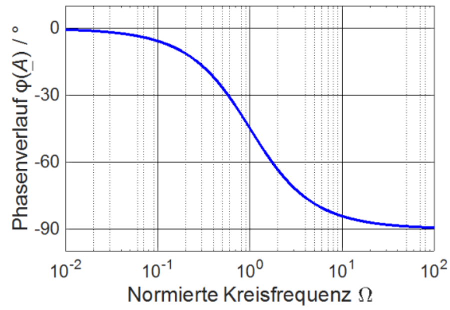
Phasengang



Tiefpassfilter ≈





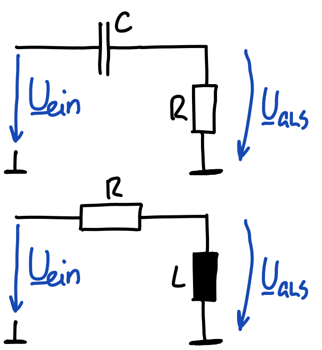


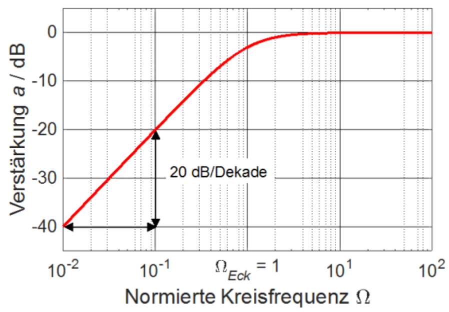
!!!

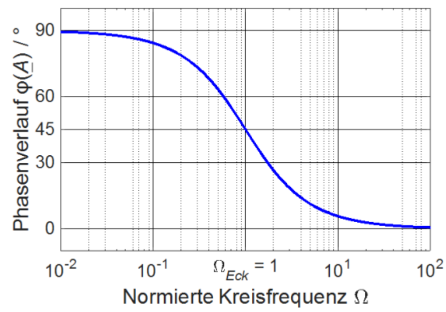
$$\boxed{\omega_G = \frac{1}{RC} = \frac{R}{L}}$$

$$\boxed{\underline{H}(j\omega) = \frac{U_{aus}}{U_{ein}} = \frac{1 - \frac{L}{R}\, j\omega}{1 + \underbrace{\left(\frac{L}{R}\right)}_{\tau}^2 \omega^2} = \frac{1 - CR\, j\omega}{1 + \underbrace{(CR)}_{\tau}^2 \omega^2}}$$

Hochpass ≈





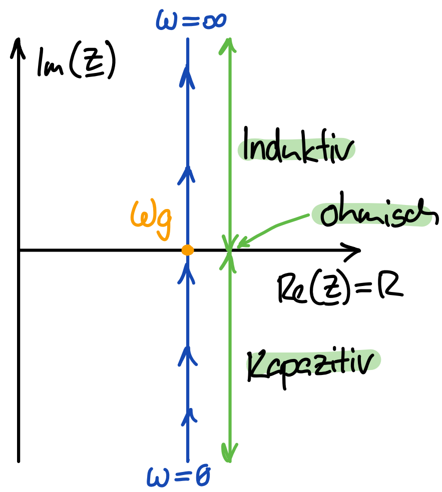


$$\boxed{\omega_G = \frac{1}{RC} = \frac{R}{L}}$$

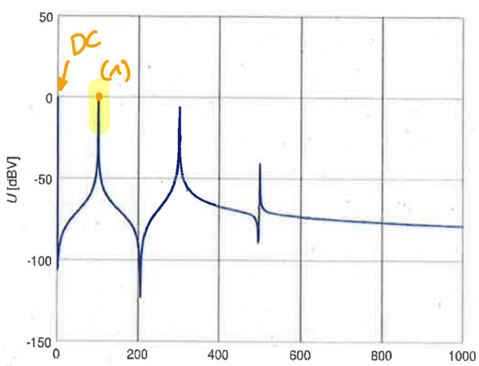
$$\boxed{\underline{H}(j\omega) = \frac{(RC)^2 \omega^2 + RC\, j\omega}{\underbrace{(RC)}_{\tau}^2 \omega^2 + 1} = \frac{\frac{L}{R} - \left(\frac{L}{R}\right)^2 j\omega}{1 + \left(\frac{L}{R}\right)^2 \omega^2}}$$

Nyquist-Diagramm

1. Gesamtwiderstand $\underline{Z}$ berechnen mit Unbekannte ωj
2. ω_G berechnen bei [$Imag(\underline{Z}) = 0$]



Fouries



FFT von $u(t)$
$U(f = 0\,\text{Hz}) = 0\,\text{dBV}$, $U(f = 100\,\text{Hz}) = 0\,\text{dBV}$,
$U(f = 300\,\text{Hz}) = -6\,\text{dBV}$, $U(f = 500\,\text{Hz}) = -40\,\text{dBV}$

$$\boxed{\frac{U_{eff}}{U_{ref}} \rightarrow 20 \cdot \log\left(\frac{U_{eff}}{U_{ref}}\right)}$$

$$\boxed{\begin{aligned} u(t) &= U_{DC} + \sqrt{2}\, U_1 \sin(\omega_1 t) + \dots \\ &= U_{DC} + \hat{U}_1 \sin(\omega_1 t) \end{aligned}}$$

Arithmetischer Mittelwert

$$\boxed{\overline{X} = \frac{1}{n} \cdot \sum_{i=1}^{n} (x_i)}$$

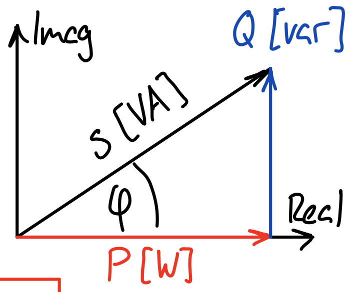
Standardabweichung

$$\boxed{S_X = \sqrt{Var} = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (x_i - \overline{x})^2}}$$

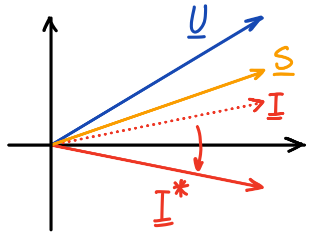
Leistung bei Wechselstrom

$$P = \frac{1}{T}\int_0^T p(t)\,dt = U_{EFF}\, I_{EFF}\, \cos(\varphi_u - \varphi_i)$$

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



Nicht vergessen!



Wirkleistung

$$P = U_{EFF}\cdot I_{EFF}\, \cos(\varphi)$$

Scheinleistung

$$S = U_{EFF}\, I_{EFF} = \sqrt{P^2 + Q^2}$$

$$\rightarrow\ \underline{U}\,\frac{\underline{U}^*}{\underline{Z}^*} = \frac{|\underline{U}|^2}{\underline{Z}^*}$$

Blindleistung

$$Q = U_{EFF}\, I_{EFF}\, \sin(\varphi)$$

$$\underline{S} = P + Qj = \underline{U}\cdot \underline{I}^*$$

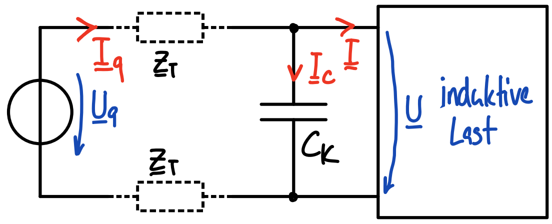
$$\varphi = \arctan\left(\frac{Q}{P}\right)$$

Blindleistungskompensation

Verlustleistung

$$P_V = 2\cdot I_q^2\, R_T$$

$$\rightarrow\ \underline{Z}_T = (R_T + X_T j)$$



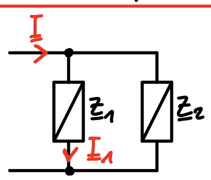
Leistungsfaktor

$$\lambda = \cos(\varphi) = \frac{P}{S}$$

Stromteiler

$$\underline{I} = \underline{I}_1\, \frac{\underline{Z}_1 + \underline{Z}_2}{\underline{Z}_2}$$

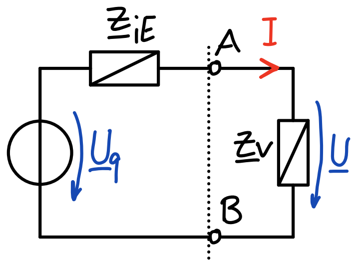
$$\underline{I}_1 = \underline{I}\, \frac{\underline{Z}_2}{\underline{Z}_1 + \underline{Z}_2}$$



Leistungsanpassung

$$P_{Vmax} = \frac{U_q^2}{4\cdot R_{iE}}$$

$$\underline{Z}_V = \underline{Z}_{iE}^*$$

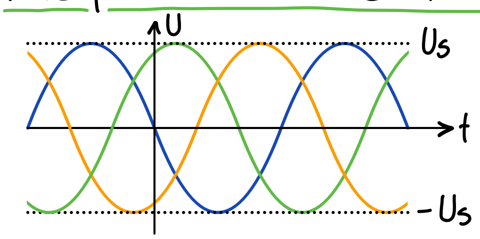


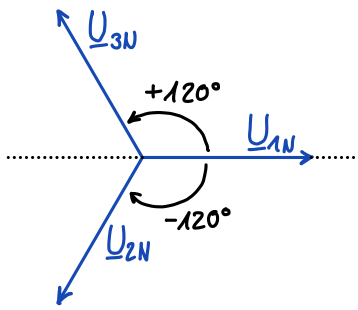
falls $\underline{Z}_V$ nur ohmisch ($\underline{Z}_V = R_V$)

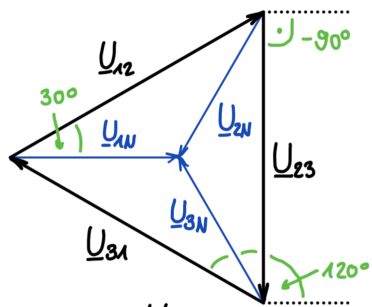
$$R_V = |\underline{Z}_i| = \sqrt{R_i^2 + X_i^2}$$

$$P_{Vmax} = I^2 R_V = \frac{U_q^2}{(R_i + R_V)^2 + X_i^2}\cdot R_V$$

Dreiphasenwechselstrom







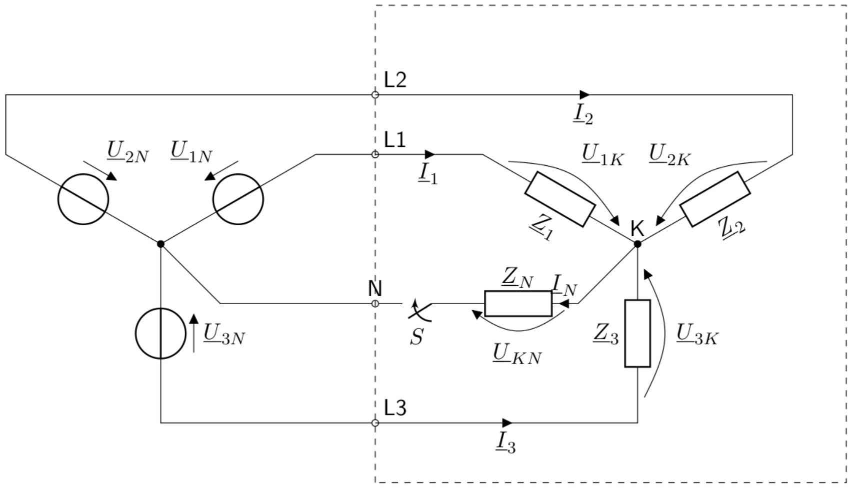
$$\underline{U}_{1N} = U_S \angle 0^\circ$$
$$\underline{U}_{2N} = U_S \angle -120^\circ$$
$$\underline{U}_{3N} = U_S \angle +120^\circ$$

$$\sum_x \underline{U}_{xN} = 0$$

$$U_\Delta = U_S\sqrt{3}$$

$$\underbrace{\underline{U}_{12}}_{U_\Delta} = \underline{U}_{1N} - \underline{U}_{2N} = U_S\cdot\sqrt{3}\angle 30^\circ$$
$$\underline{U}_{23} = \underline{U}_{2N} - \underline{U}_{3N} = U_S\cdot\sqrt{3}\angle -90^\circ$$
$$\underline{U}_{31} = \underline{U}_{3N} - \underline{U}_{1N} = U_S\cdot\sqrt{3}\angle 150^\circ$$

Sternschaltung



bei Symmetrie

$$\boxed{\underline{Z}_1 = \underline{Z}_2 = \underline{Z}_3 = Z \angle \varphi_Z}$$

$$\boxed{\underline{I}_1 = \underline{I}_2 = \underline{I}_3 = \underline{I} = \frac{\underline{U}_S}{\underline{Z}}} \qquad \boxed{\underline{I}_n = \frac{\underline{U}_{nN}}{\underline{Z}_n}}$$

$$\boxed{\underline{U}_{KN} = 0} \qquad \boxed{\underline{U}_{nK} = \underline{U}_{nN}}$$

$$\boxed{\underline{S} = 3 \cdot \underline{S}_1 = 3\, \underline{I}\, \underline{U}_S = 3 \frac{U_S^2}{\underline{Z}}}$$

$P = S \cdot \cos(\varphi)$; $Q = S \cdot \sin(\varphi_Z)$

Unsymmetrisch

$$\boxed{\underline{S}_n = \underline{U}_{nK}\, \underline{I}_n^* = \frac{U_{nK}^2}{\underline{Z}_n^*}}$$

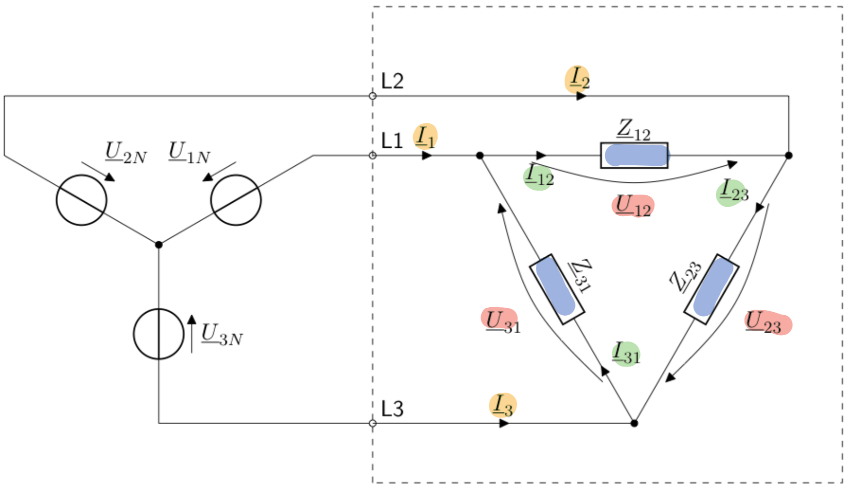
$$\boxed{\underline{U}_{KN} = \frac{\frac{\underline{U}_{1N}}{\underline{Z}_1} + \frac{\underline{U}_{2N}}{\underline{Z}_2} + \frac{\underline{U}_{3N}}{\underline{Z}_3}}{\frac{1}{\underline{Z}_1} + \frac{1}{\underline{Z}_2} + \frac{1}{\underline{Z}_3} + \frac{1}{\underline{Z}_N}}}$$

$$\boxed{\underline{I}_n = \underline{I}_1 + \underline{I}_2 + \underline{I}_3}$$

$$\left(\underline{S} = \sum \frac{U_{nK}^2}{\underline{Z}_n^*} \right)$$

Schalter offen: $\underline{I}_N = 0$ Schalter zu: $\underline{I}_N = \underline{I}_1 + \underline{I}_2 + \underline{I}_3$ $\underline{Z}_N = 0$: $\underline{U}_{KN} = 0$

Dreieckschaltung



Allgemein

$$\boxed{\underline{I}_x = \frac{\underline{U}_x}{\underline{Z}_x}} \qquad x \to 12, 23, 31$$

$$\boxed{\underline{I}_1 = \underline{I}_{12} - \underline{I}_{31} \qquad \underline{I}_2 = \underline{I}_{23} - \underline{I}_{12} \qquad \underline{I}_3 = \underline{I}_{31} - \underline{I}_{23}}$$

Symmetrisch

$$\boxed{\underline{Z}_{12} = \underline{Z}_{23} = \underline{Z}_{31} = Z \angle \varphi}$$

$$\boxed{\underline{S} = 3\, \underline{S}_{nm} = 3 \frac{U^2}{\underline{Z}^*}}$$

$S = \frac{U^2}{Z}$; $P = S \cos(\varphi_Z)$; $Q = S \sin(\varphi_Z)$

Unsymmetrisch

Strangströme & -Leistungen müssen einzel berechnet werden!

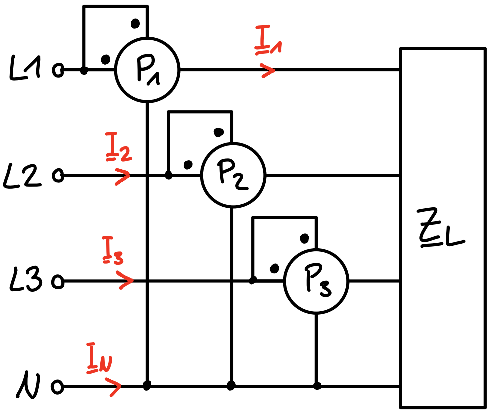
$$\boxed{\begin{aligned} \underline{S} &= \underline{S}_1 + \underline{S}_2 + \underline{S}_3 = \underline{U}_{12}\, \underline{I}_{12}^* + \underline{U}_{23}\, \underline{I}_{23}^* + \underline{U}_{31}\, \underline{I}_{31}^* \\ &= U^2 \left(\frac{1}{\underline{Z}_{12}^*} + \frac{1}{\underline{Z}_{23}^*} + \frac{1}{\underline{Z}_{31}^*} \right) \end{aligned}}$$

$$\boxed{\underline{S}_x = \frac{U^2}{\underline{Z}_x}} \quad \boxed{P_x = S_x \cos(\varphi_{Zx})} \quad \boxed{Q_x = S_x \sin(\varphi_{Zx})} \qquad x \to 12, 23, 31$$

$$\boxed{P = P_{12} + P_{23} + P_{31}} \quad \boxed{Q = Q_{12} + Q_{23} + Q_{31}}$$

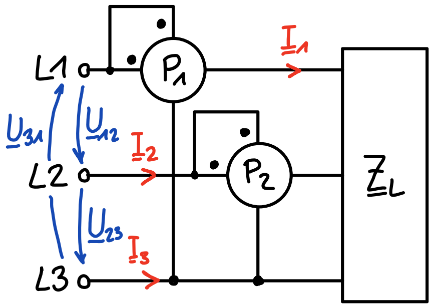
Leistungsmessung im Drehstromnetz

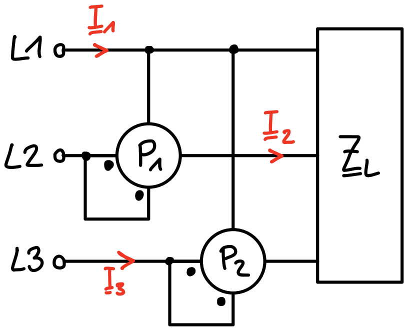
4 Leiter (mit Nullleiter)

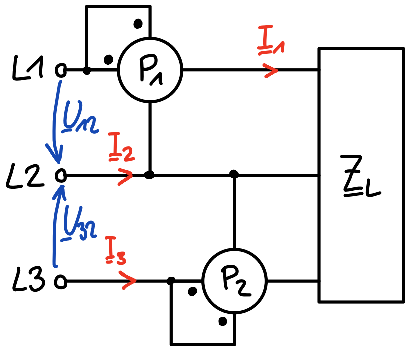


$$\boxed{P = P_1 + P_2 + P_3}$$

3 Leiter (ohne Nullleiter)







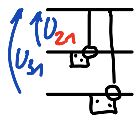
$$\boxed{P = P_1 + P_2}$$

$$\underline{S}_1 = (\underline{U}_{1n} - \underline{U}_{2n}) \cdot \underline{I}_1$$

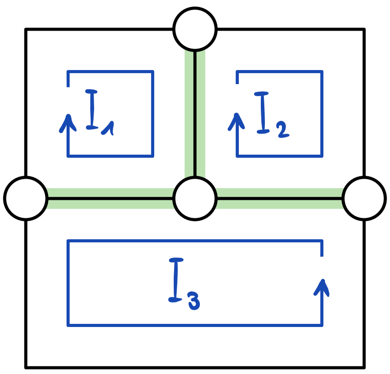
$$\underline{S}_2 = (\underline{U}_{3n} - \underline{U}_{2n}) \cdot \underline{I}_3$$

Sternenschaltung

$$\underline{S} = \underline{U}_{31} \cdot \underline{I}_3^* + \underline{U}_{21} \cdot \underline{I}_2^*$$



Maschenstrom-/Umlaufanalyse



vollständiger Baum

I_{I}	I_{II}	I_{III}	=
$\sum \underline{Z}_{I}$	$\pm \sum \underline{Z}_{I-II}$	$\pm \sum \underline{Z}_{I-III}$	$\sum \pm \underline{U}_{I}$
$\pm \sum \underline{Z}_{I-II}$	$\sum \underline{Z}_{II}$	$\pm \sum \underline{Z}_{II-III}$	$\sum \pm \underline{U}_{II}$
$\pm \sum \underline{Z}_{I-III}$	$\pm \sum \underline{Z}_{II-III}$	$\sum \underline{Z}_{III}$	$\sum \pm \underline{U}_{III}$

$$\boxed{m = z - k + 1}$$

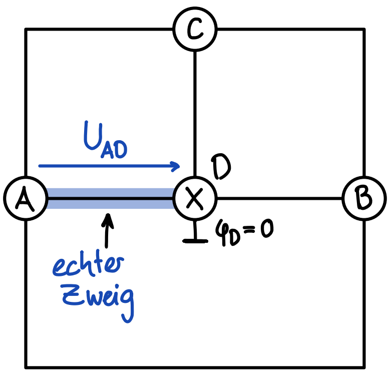
Maschenverbindung
- max. 1 Verbindungskante
- rest mit Baumkanten

- Stromquellen bestimmen unbekannte Ströme → R · I Gleichungen auf Spannungsseite

$$\underbrace{R_1 \cdot I_1}_{} + R_2 \cdot I_2 = U_1 - R_1 \cdot I_1$$

$$| - R_1 \cdot I_1$$

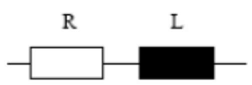
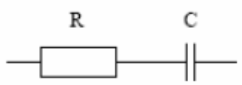
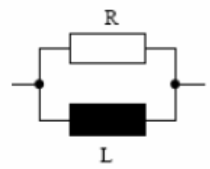
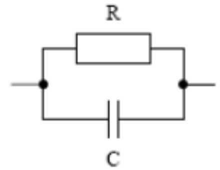
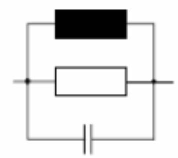
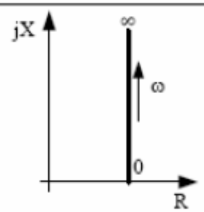
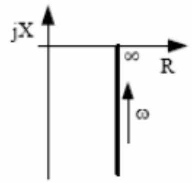
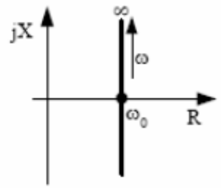
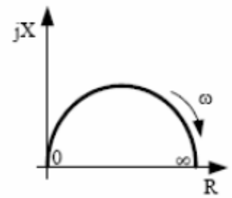
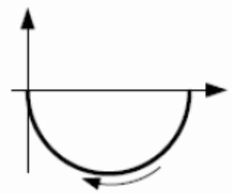
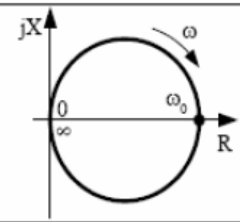
Knotenpotential-/Knotenanalyse



φ_A	φ_B	φ_C	=
$\sum \underline{Y}_A$	$-\sum \underline{Y}_{A-B}$	$-\sum \underline{Y}_{A-C}$	$\sum \pm I_A$
$-\sum \underline{Y}_{A-B}$	$\sum \underline{Y}_B$	$-\sum \underline{Y}_{B-C}$	$\sum \pm I_B$
$-\sum \underline{Y}_{A-C}$	$-\sum \underline{Y}_{B-C}$	$\sum \underline{Y}_C$	$\sum \pm I_C$

- Spannungsquellen bestimmen die Potentiale → Potentiale reduzieren

Ortskurven einfacher Serien- und Parallelschaltungen

Schaltung						
Scheinwiderstand	$\underline{Z} = R + j\omega L$	$\underline{Z} = R - j\dfrac{1}{\omega C}$	$\underline{Z} = R + j\left(\omega L - \dfrac{1}{\omega C}\right)$	$\underline{Z} = \dfrac{1}{\dfrac{1}{R} - j\dfrac{1}{\omega L}}$	$\underline{Z} = \dfrac{1}{\dfrac{1}{R} + j\omega C}$	$\underline{Z} = \dfrac{1}{\dfrac{1}{R} + j\left(\omega C - \dfrac{1}{\omega L}\right)}$
Betrag des Schein-widerstandes	$Z = \sqrt{R^2 + (\omega L)^2}$	$Z = \sqrt{R^2 + \left(\dfrac{1}{\omega C}\right)^2}$	$Z = \sqrt{R^2 + \left(\omega L - \dfrac{1}{\omega C}\right)^2}$	$Z = \dfrac{1}{\sqrt{\left(\dfrac{1}{R}\right)^2 + \left(\dfrac{1}{\omega L}\right)^2}}$	$Z = \dfrac{1}{\sqrt{\left(\dfrac{1}{R}\right)^2 + (\omega C)^2}}$	$Z = \dfrac{1}{\sqrt{\left(\dfrac{1}{R}\right)^2 + \left(\omega C - \dfrac{1}{\omega L}\right)^2}}$
Phase	$\varphi_Z = \arctan\dfrac{\omega L}{R}$	$\varphi_Z = -\arctan\dfrac{1}{\omega R C}$	$\varphi_Z = \arctan\dfrac{\omega L - \dfrac{1}{\omega C}}{R}$	$\varphi_Z = \arctan\dfrac{R}{\omega L}$	$\varphi_Z = -\arctan(\omega R C)$	$\varphi_Z = -\arctan\left[R\left(\omega C - \dfrac{1}{\omega L}\right)\right]$
Ortskurve des Schein-widerstandes						
Scheinleitwert	$\underline{Y} = \dfrac{1}{R + j\omega L}$	$\underline{Y} = \dfrac{1}{R - j\dfrac{1}{\omega C}}$	$\underline{Y} = \dfrac{1}{R + j\left(\omega L - \dfrac{1}{\omega C}\right)}$	$\underline{Y} = \dfrac{1}{R} - j\dfrac{1}{\omega L}$	$\underline{Y} = \dfrac{1}{R} + j\omega C$	$\underline{Y} = \dfrac{1}{R} + j\left(\omega C - \dfrac{1}{\omega L}\right)$
Betrag des Schein-leitwertes	$Y = \dfrac{1}{\sqrt{R^2 + (\omega L)^2}}$	$Y = \dfrac{1}{\sqrt{R^2 + \left(\dfrac{1}{\omega C}\right)^2}}$	$Y = \dfrac{1}{\sqrt{R^2 + \left(\omega L - \dfrac{1}{\omega C}\right)^2}}$	$Y = \sqrt{\left(\dfrac{1}{R}\right)^2 + \left(\dfrac{1}{\omega L}\right)^2}$	$Y = \sqrt{\left(\dfrac{1}{R}\right)^2 + (\omega C)^2}$	$Y = \sqrt{\left(\dfrac{1}{R}\right)^2 + \left(\omega C - \dfrac{1}{\omega L}\right)^2}$
Phase	$\varphi_Y = -\arctan\dfrac{\omega L}{R}$	$\varphi_Y = \arctan\dfrac{1}{\omega R C}$	$\varphi_Y = -\arctan\dfrac{\omega L - \dfrac{1}{\omega C}}{R}$	$\varphi_Y = -\arctan\dfrac{R}{\omega L}$	$\varphi_Y = \arctan(\omega R C)$	$\varphi_Y = \arctan\left[R\left(\omega C - \dfrac{1}{\omega L}\right)\right]$
Ortskurve des Schein-leitwertes