empirischer Mittelw. $\bar{x} = \frac{1}{N}\sum_{i=1}^{N} x_i$

emp. Var. $s^2 = \frac{1}{N-1}\sum_{i=1}^{N}(x_i - \bar{x})^2$

emp. Standardabw. $s = \sqrt{s^2}$

Verteilungsfkt. $F_x(x) = \int_{-\infty}^{x} f_x(x)\,dx$

Erwartungswert
d: $\mu = E\{x\} = \sum_i x_i \cdot P(x = x_i)$
k: $\mu = \int_{-\infty}^{\infty} x \cdot f_x(x)\,dx$

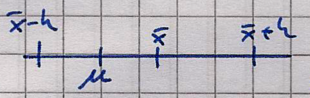
Standardabw. $\sigma = \sqrt{Var\{x\}} = \sqrt{E\{(x-\mu)^2\}}$

Gaußverteilung $F_g(x) = \exp\left(\frac{(x-\mu)^2}{2 \cdot Var}\right) \cdot \frac{1}{2\pi\sigma}$

Varianz
k: $Var\{x\} = \int_{-\infty}^{\infty} (x-\mu)^2 \cdot f_x(x)\,dx$
d: $= \sum_i (x_i - \mu)^2 \cdot P(x = x_i)$

normierte H. $h_n = \frac{H_A}{\Delta x \cdot N}$

Vertrauensintervall
σ bekannt: $V_{1,2} = \bar{x} \pm \frac{t\sigma}{\sqrt{N}}$
σ unbek.: $V_{1,2} = \bar{x} \pm \frac{t_p s}{\sqrt{N}}$



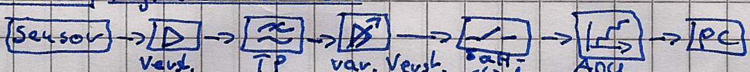
Bedingungen für kub. Splines
1) Interpolationsbed.: $s_i(x_i) = y_i \mid i = 0 \dots N$
2) Stetigkeit in d. Stützst.: $s_i(x_i) = s_{i-1}(x_i) \mid i = 0 \dots N-1$
3) Stetigkeit der 1. Abl.: $s_i'(x_i + 0) = s_{i-1}'(x_i - 0) \mid i = 1 \dots N-1$
4) Stetigkeit der 2. Abl.: $s_i''(x_i + 0) = s_{i-1}''(x_i - 0) \mid i = 1 \dots N-1$
5) Gleiche Krümmung a. d. R.: $s_0''(x_0) = s_{N-1}''(x_N)$

Transformation
$u_{aus} = 1 - e^{a\,klein}$
$1 - u_{aus} = e^{a\,klein}$
$\ln(1-u_{aus}) = a\,klein$

Grenzfrequenz d. Haltekreises
$f_g = \sqrt{\frac{6 \cdot u_{LSB}}{u_{max} - u_{min}}} \cdot \frac{1}{\pi T}$

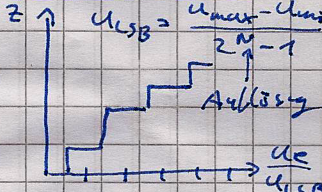
Methode d. kl. Fehlerquadrate
$\hat{a} = (X^T \cdot X)^{-1} \cdot X^T \cdot y$
Ansatz:
$\hat{y}_i = b x_i + a$ $e_i = (y_i - \hat{y}_i)$
$= y_i - b x_i - a$
$E = \sum e_i^2$ → ableiten und null setzen
$\frac{\partial \sum e_i^2}{\partial a} = 0$ ...

Digitale Messkette
Sensor → Verst. → TP → var. Verst. → S&H-Glied → ADU → PC

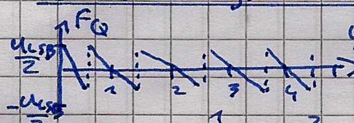


$\frac{S}{R} = 20\log\left(\frac{u}{\sigma}\right)$
$= 20\log\left(\frac{\sqrt{3}}{\sqrt{2}}(2^N - 1)\right)$

ADU-Kennlinie
$u_{LSB} = \frac{u_{max} - u_{min}}{2^N - 1}$
Auflösung



Quantisierungsrauschen
F_Q, $\frac{u_{LSB}}{2}$, $-\frac{u_{LSB}}{2}$, $\frac{u_e}{u_{LSB}}$



F_Q $\sigma = \frac{1}{12} u_{LSB}^2$

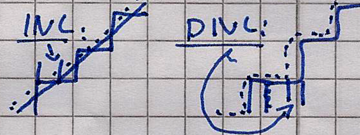
max Frequ.: $f_g = \frac{u_{LSB}}{2 \cdot \pi \cdot \hat{u} T_c}$

Streuung: $u_N = \frac{u_{LSB}}{\sqrt{12}}$

$F_Q \leq \pm\frac{1}{2} u_{LSB}$

SNR

INL: **DNL:**



Aliasingfilter
Frequenzen $w_g > \frac{w_0}{2}$ dämpfen: $|A_F(w_0/2)|_{dB} \geq 20 \cdot \log\left(\frac{u_{max} - u_{min}}{u_{LSB}}\right) = 20 \cdot \log(2^N - 1)\,dB \approx 6{,}02 N \cdot dB$

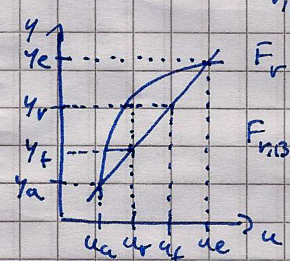
Filterordnung: $\frac{\Delta y}{\Delta x} = \frac{|A_F(w_0/2)|\,dB}{\log_{10}\left(\frac{w_0/2}{w_g}\right) - \log_{10}(1)}$

Gleichrichtwert $|\bar{i}| = \frac{1}{T}\int_t^{t+T} |i(t)|\,dt$

RMS-Wert $I = \sqrt{\frac{1}{T}\int_t^{t+T} i^2(t)\,dt}$

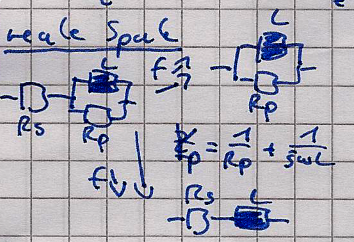
realer Kondensator
$f\uparrow$: $Z_s = R_s + \frac{1}{j\omega C}$
$f\downarrow$
$\tan\delta = \frac{1}{Q}$
$= \frac{1}{\omega R_p \cdot C_p}$
$= \frac{R_s}{\omega C_s}$
$Y_p = \frac{1}{R_p} + j\omega C$
$Z_p = \frac{R_p}{1 + j\omega R_p C}$

Kennlinienfehler
$F_{rA} = \frac{y_r - y_f}{y_f}$ $F_{rE} = \frac{y_r - y_f}{y_e}$
$F_r = \frac{y_r - y_f}{y_f - y_a}$
$F_{rB} = \frac{y_r - y_f}{y_e - y_a}$



$\tan\delta = \frac{1}{Q}$
$= \omega R_s L_s$
$= \frac{\omega L_p}{R_p}$

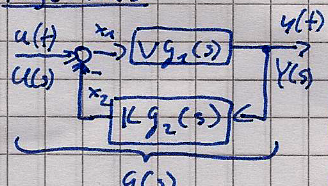
reale Spule
$f\uparrow$ R_s R_p
$f\downarrow$ $Y_p = \frac{1}{R_p} + \frac{1}{j\omega L}$
$Z_s = R_s + j\omega L$



Signalformen

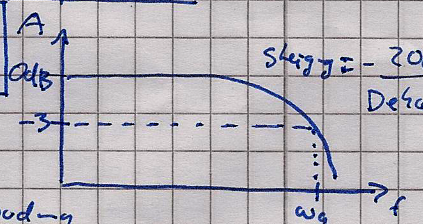
	F-Fkt.	C-Fkt.
Rechteck	1	1
Dreieck	$\sqrt{3}$	$\frac{2}{\sqrt{3}}$
Sinus	2	$\frac{\pi}{2\sqrt{2}}$

Regelkreis



$G(s) = \frac{Y(s)}{U(s)} = \frac{V g_1(s)}{1 + V g_1(s) \cdot K g_2(s)}$

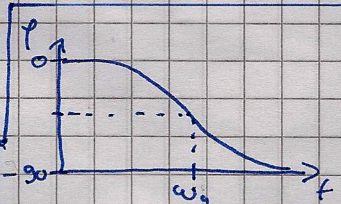
Tiefpassfilter



Steigung $= -20\,\mathrm{dB}$ / Dekade

$f_c = \frac{1}{2\pi R \cdot C}$

1. Ordnung



mit Lu. R. s. 2. Seite

max. Fehlergrenzen für komplexe Widerstand
$\Delta z = \left|\frac{\partial z}{\partial R} \cdot g_R\right| + \left|\frac{\partial z}{\partial C} \cdot g_C\right| = g_z$

allg.:
$g = \pm\sum_{i=1}^{N}\left|\frac{\partial y}{\partial x_i} g_i\right|$

Charakteristika der Sprungantwort

Einschwingzeit t_e: zw. Spd. Tangente in $0{,}5 h_\infty$ und h_∞

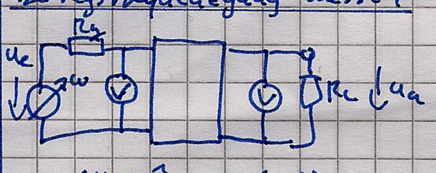
Anstiegszeit: $t_r = t_{90} - t_{10}$ Sprungantwort von 10% auf 90% des Endwertes

Einstellzeit t_s: det. Toleranzband wird nicht mehr verlassen

Verzugszeit: t_v: zw. Sprungeinsatz und Schnittp. von Wendetang. mit Nulllinie

Ausgleichszeit: t_g: zw. Schnittp. der WT u. NL und stat. Wert

Betragsfrequenzgang messen



$u_e(t) = \hat{u}_e \sin(\omega t)$
$u_a(t) = \hat{u}_a \sin(\omega t + \varphi)$

Leistungsmessung $U_{eff} = \frac{\hat{u}}{\sqrt{2}}$

u~, i~

$p(t) = P + S\cos(2\omega t + \varphi_u + \varphi_i)$

$P = U \cdot I \cdot \cos\varphi = S \cdot \cos\varphi$

$Q = U \cdot I \cdot \sin\varphi = S \cdot \sin\varphi$

$S = U \cdot I$

W.F. $\lambda = \frac{P}{S} = \cos\varphi$ Bl.F. $\sin\varphi = \frac{Q}{S}$

u~, i⊓

$P = U \cdot I_1 \cdot \cos\varphi_1$

$S = U \cdot \sqrt{I_1^2 + I_2^2 + \ldots + I_N^2}$

$Q_1 = U \cdot I_1 \cdot \sin\varphi_1$

$D = U\sqrt{I_2^2 + I_3^2 + \ldots + I_N^2}$

$Q = \sqrt{Q_1^2 + D^2}$

L.F. $\lambda = \frac{P}{S} = \frac{I_1}{I}\cos\varphi_1 = g \cdot \cos\varphi_1$

Wirkleistung

u, i — $\boxed{\times}$ — $\boxed{\int}$ — $\boxed{\frac{1}{T}}$ → P

Blindleistung

u — $\boxed{90°}$, i — $\boxed{\times}$ — $\boxed{\int}$ — $\boxed{\frac{1}{T}}$ → Q

Scheinleistung

u — $\boxed{(\,)^2}$ — $\boxed{\int}$ — $\boxed{\frac{1}{T}}$

i — $\boxed{(\,)^2}$ — $\boxed{\int}$ — $\boxed{\frac{1}{T}}$ — $\boxed{\times}$ — $\boxed{\sqrt{\,}}$ — S

mit Dimmer

$P(\vartheta) = \frac{1}{2\pi}\int_0^{2\pi} u(\omega t)\cdot i(\omega t,\vartheta)\,d\omega t$

$= \frac{1}{\pi}\int_\vartheta^\pi \hat{u}\sin(\omega t)\cdot \hat{i}\sin(\omega t)\,d\omega t$

$= \frac{\hat{u}\,\hat{i}}{2\pi}\int_\vartheta^\pi \sin^2(\omega t)\,d\omega t$

$= \frac{\hat{u}\,\hat{i}}{2\pi}\left(\pi - \vartheta + \frac{1}{2}\sin(2\vartheta)\right)$

Strom am Dimmer

$I = \sqrt{\frac{1}{T}\int_0^T i^2(t)\,dt}$

$= \hat{i}\sqrt{\frac{1}{2\pi}\left(\pi - \vartheta + \frac{1}{2}\sin(\vartheta)\right)}$

Scheinleistung am Dimmer

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

Verzerrungsleistung

$D = \sqrt{(U_{eff}\cdot I_{eff})^2 - P^2 - Q_1^2}$

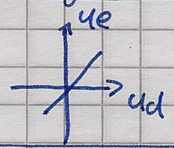
Wechselstrommessbrücke

1\. Abgleichbed.: $\frac{Z_1}{Z_2} = \frac{Z_3}{Z_4}$

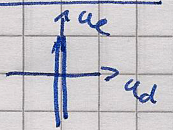
2\. Abgleichbed.: $\varphi_1 - \varphi_2 = \varphi_3 - \varphi_4$

Empfindlichkeit: $\frac{\partial U}{\partial Z_x}$

Phasengleichheit



Phase + Betrag



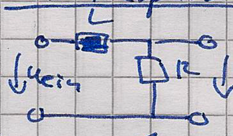
statistische Sicherheit

$V_{1,2} = \bar{x} \pm \frac{t \cdot \sigma}{\sqrt{N}}$ ← aus Tabelle

Filterordnung Aliasing Filter

$$\frac{-20\log_{10}\left(\frac{u_{LSB}}{u_{max}-u_{min}}\right)}{\log_{10}\left(\frac{\omega_s}{2\omega_g}\right)}$$

L-R-Tiefpass 1. Ord

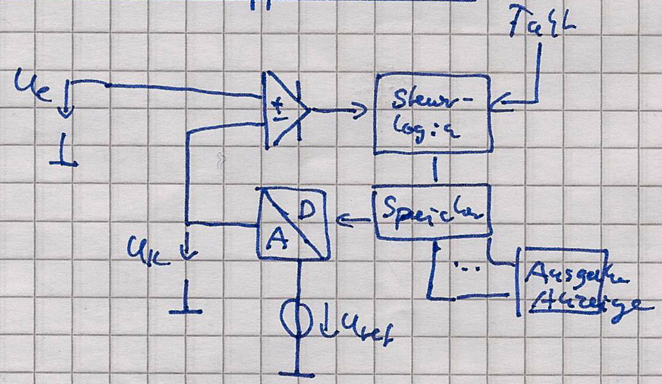


$f_g = \frac{1}{2\pi} \cdot \frac{R}{L}$

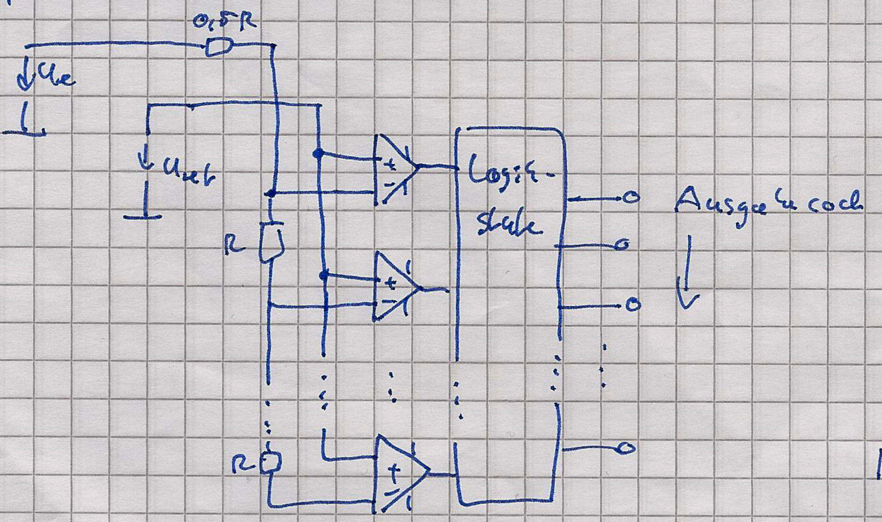
$A(\omega) = \frac{u_{aus}}{u_{ein}} = \frac{1}{\sqrt{1 + \left(\frac{\omega \cdot L}{R}\right)^2}}$

$G(s) = \frac{u_a}{u_e} = \frac{1}{s \cdot \frac{L}{R} + 1}$

Sukzessive Approximation



paralleles Umsetzverfahren



Klausureinsicht 04.03.2013
13 Uhr, EN 403