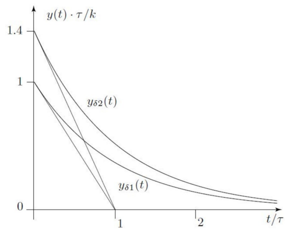
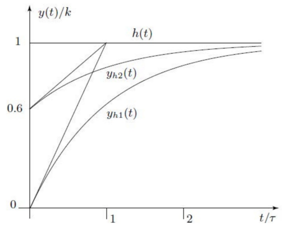
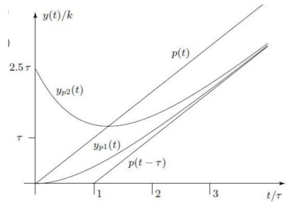
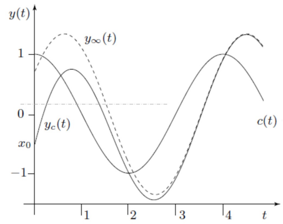
Regelungstechnik: *FAST Reference sheet*

Dino Colombo, Michael van Huffel

August 6, 2021

Testsignale 1. Ordnung

Name	Impulse	Step	Ramp	Harmonic
Picture				
Input	$\delta(t) = \lim_{\Delta\to\infty} \begin{cases} \Delta, & t < \frac{1}{\Delta} \\ 0, & t \geq \frac{1}{\Delta} \end{cases}$	$h(t) = \begin{cases} 0, & t < 0 \\ 1, & t \geq 0 \end{cases}$	$p(t) = h(t) \cdot t$	$c(t) = h(t) \cdot \cos(\omega t)$
Output	$y_\delta(t) = e^{\frac{-t}{\tau}} \cdot (x_0 + \frac{k}{\tau})$	$y_h(t) = e^{\frac{-t}{\tau}} \cdot x_0 + k \cdot (1 - e^{\frac{-t}{\tau}})$	$y_p(t) = e^{-\frac{t}{\tau}} x_0 + k(t + (e^{-\frac{t}{\tau}} - 1)\tau)$	$y_{c,\infty} = m(\omega) \cdot \cos(\omega t + \varphi(\omega))$

Aussage über ein system

Lyapunov Stabilität

1. **Asymptotisch stabil:** $\lim\limits_{t\to\infty} \|x(t)\| = 0$, falls alle EW $\mathrm{Re}(\lambda_i) < 0$.
2. **Stabil:** $(\|x(t)\| < \infty \forall t \in [0, \infty])$, falls mehrere EW $\mathrm{Re}(\lambda_k) = 0$ und kein EW $\mathrm{Re}(\lambda_i) \not> 0$.
3. **Instabil:** $\lim\limits_{t\to\infty} \|x(t)\| = \infty$ falls mindestens ein EW $\mathrm{Re}(\lambda_i) > 0$.

BIBO Stabilität

Ein System ist BIBO Stabil, falls für die Impulsantwort $\delta(t)$ folgendes gilt: $\int_0^\infty |\delta(t)| dt < \infty$

- $Re(\pi_i) < 0, \forall i \in \mathcal{N}$
- Nicht BIBO stabil in allen anderen Fällen.

-barkeit

- **Steuer-/Erreich-**: $\mathcal{R} = \begin{bmatrix} b, & A \cdot b, & A^2 \cdot b, & \ldots, & A^{n-1} \cdot b \end{bmatrix}$: vollen Rang ($\mathrm{Det}(\mathcal{R}) \neq 0$).
- **Stabilisier-**: Ein (instabiles) System ist potentiell Stabilisierbar, falls alle Zustände, die nicht steuerbar sind asymptotisch stabil sind.
- **Beobachtbar-**: $\mathcal{O} = \begin{bmatrix} c \\ c \cdot A \\ c \cdot A^2 \\ \vdots \\ c \cdot A^{n-1} \end{bmatrix}$: vollen Rang ($\mathrm{Det}(\mathcal{O}) \neq 0$)
- **Detektier-**: Ein System ist nur detektierbar, falls alle seine nicht-beobachtbaren Zustände asymptotisch stabil sind.

Übertragungsfunktion

Achtung: #Pole = Ordnung des Systems
$\Sigma(s) = \frac{Y(s)}{U(s)} = \frac{c \cdot \mathrm{Adj}(s\mathbb{I} - A) \cdot b}{\det(s\mathbb{I} - A)} + d$

Most common $adj()$

Adjunkte für eine $n \times n$ Matrix:

$$adj(A) = C^T = ((-1)^{i+j} M_{ji})_{1 \le i,j \le n}$$

Adjunkte für eine 2×2-Matrix:

$$A = \begin{bmatrix} a & b \\ c & d \end{bmatrix} \xRightarrow{adjungieren} \text{Adj}(A) = \begin{bmatrix} d & -b \\ -c & a \end{bmatrix}$$

Adjunkte für eine 3×3-Matrix:

$$adj \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix} = C^T = \begin{pmatrix} +\det \begin{pmatrix} a_{22} & a_{23} \\ a_{32} & a_{33} \end{pmatrix} & -\det \begin{pmatrix} a_{12} & a_{13} \\ a_{32} & a_{33} \end{pmatrix} & +\det \begin{pmatrix} a_{12} & a_{13} \\ a_{22} & a_{23} \end{pmatrix} \\ -\det \begin{pmatrix} a_{21} & a_{23} \\ a_{31} & a_{33} \end{pmatrix} & +\det \begin{pmatrix} a_{11} & a_{13} \\ a_{31} & a_{33} \end{pmatrix} & -\det \begin{pmatrix} a_{11} & a_{13} \\ a_{21} & a_{23} \end{pmatrix} \\ +\det \begin{pmatrix} a_{21} & a_{22} \\ a_{31} & a_{32} \end{pmatrix} & -\det \begin{pmatrix} a_{11} & a_{12} \\ a_{31} & a_{32} \end{pmatrix} & +\det \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix} \end{pmatrix}$$

Laplace-Transformation

Wichtige Singaltransformationen:

$x(t)$	$X(S)$
$\delta(t)$	1
$h(t) \quad (=1)$	$\frac{1}{s}$
$p(t) \quad (=t)$	$\frac{1}{s^2}$
$h(t) \cdot t^n \cdot e^{\alpha \cdot t}$	$\frac{n!}{(s-\alpha)^{n+1}}$
$h(t) \cdot sin(\omega \cdot t)$	$\frac{\omega}{s^2+\omega^2}$
$h(t) \cdot cos(\omega \cdot t)$	$\frac{s}{s^2+\omega^2}$
$h(t) \cdot sinh(\omega \cdot t)$	$\frac{\omega}{s^2-\omega^2}$
$h(t) \cdot cosh(\omega \cdot t)$	$\frac{s}{s^2-\omega^2}$
$h(t) \cdot (e^{at} - 1)$	$\frac{a}{s(s-a)}$
$h(t) \cdot \frac{e^{at}-e^{bt}}{a-b}$	$\frac{1}{(s-a)(s-b)}$
$h(t) \cdot \frac{ae^{at}-be^{bt}}{a-b}$	$\frac{s}{(s-a)(s-b)}$

Wichtige Eigenschaften:

Linearität	$\mathcal{L}\{ax_1(t) + bx_2(T)\} = aX_1(s) + bX_2(s)$
Ähnlichkeit	$\mathcal{L}\{\frac{1}{a} \cdot x(\frac{t}{a})\} = X(s \cdot a)$
Verschiebung	$\mathcal{L}\{x(t-T)\} = e^{-T \cdot s} \cdot X(S)$
Dämpfung	$\mathcal{L}\{(x(t) \cdot e^{a \cdot t}\} = X(s-a)$
Ableitung t	$\mathcal{L}\{\frac{d}{dt}x(t)\} = s \cdot X(s) - x(0)$
2. Ableitung t	$\mathcal{L}\{\frac{d^2}{dt^2}x(t)\} = s^2 \cdot X(s) - s \cdot x(0) - \frac{d}{dt}x(0)$
$n-$te Abl. t	$s^n \cdot X(s) - s^{n-1}x(0) - \cdots - s^0 \frac{d^{n-1}}{dt^{n-1}}$
Ableitung s	$\mathcal{L}\{t \cdot x(t)\} = -\frac{d}{ds}X(s)$
Integration t	$\mathcal{L}\{\int_0^t x(\tau)d\tau\} = \frac{1}{s} \cdot X(s)$
Integration s	$\mathcal{L}\{\frac{1}{t} \cdot x(t)\} = \int_s^\infty X(\sigma)d\sigma$
Convolution t	$\mathcal{L}\{x_1(t) * x_2(t)\} = X_1(s) \cdot X_2(s)$
Convolution s	$\mathcal{L}\{x_1(t) \cdot x_2(t)\} = X_1(s) * X_2(s)$
Anfangswert	$\lim_{t \to 0^+} x(t) = \lim_{s \to \infty} s \cdot X(s)$
Endwert	$\lim_{t \to \infty} x(t) = \lim_{s \to 0} s \cdot X(s)$

dB Skala

Dec	dB	dB	Dec
∞	∞	∞	∞
1000	60	1000	$1 \cdot 10^{50}$
100	40	100	$100000 = 10^5$
50	33.98	80	$10000 = 10^4$
20	26.02	60	$1000 = 10^3$
10	20	40	100
9	19.08	30	31.62
8	18.06	20	10
7	16.90	15	5.62
6	15.56	10	$3.16 = \sqrt{10}$
5	13.98	9	2.82
4	12.04	8	2.51
3	9.54	7	2.24
2	6.02	6	≈ 2
1	0	5	$1.78 = \sqrt[4]{10}$
$\frac{1}{2} = 0.5$	-6.02	4	1.58
$\frac{1}{3} \approx 0.33$	-9.54	3	$1.41 \approx \sqrt{2}$
$\frac{1}{4} = 0.25$	-12.04	2	$1.26 = \sqrt[10]{10}$
$\frac{1}{5} = 0.2$	-13.98	1	$1.12 = \sqrt[20]{10}$
$\frac{1}{6} \approx 0.17$	-15.56	0.1	≈ 1.01
$\frac{1}{7} \approx 0.14$	-16.90	0.01	≈ 1.001
0.1	-20.00	0	1
0.01	-40.00	$x_{dB} < 0$	$-\frac{1}{x_{dec}}$
0	$-\infty$	$-\infty$	0

$$\frac{1}{x_{dB}} = -x_{dB} \leftrightarrow \frac{1}{5dB} = -5dB$$

Trigonometric function

α deg	α rad	$\cos(\alpha)$	$\sin(\alpha)$	$\tan(\alpha)$	$\cot(\alpha)$
$0°$	0	1	0	0	$-$
$30°$	$\frac{\pi}{6}$	$\frac{\sqrt{3}}{2}$	$\frac{1}{2}$	$\frac{\sqrt{3}}{3}$	$\sqrt{3}$
$45°$	$\frac{\pi}{4}$	$\frac{\sqrt{2}}{2}$	$\frac{\sqrt{2}}{2}$	1	1
$60°$	$\frac{\pi}{3}$	$\frac{1}{2}$	$\frac{\sqrt{3}}{2}$	$\sqrt{3}$	$\frac{\sqrt{3}}{3}$
$90°$	$\frac{\pi}{2}$	0	1	$-$	0

Einfluss von Nullstellen

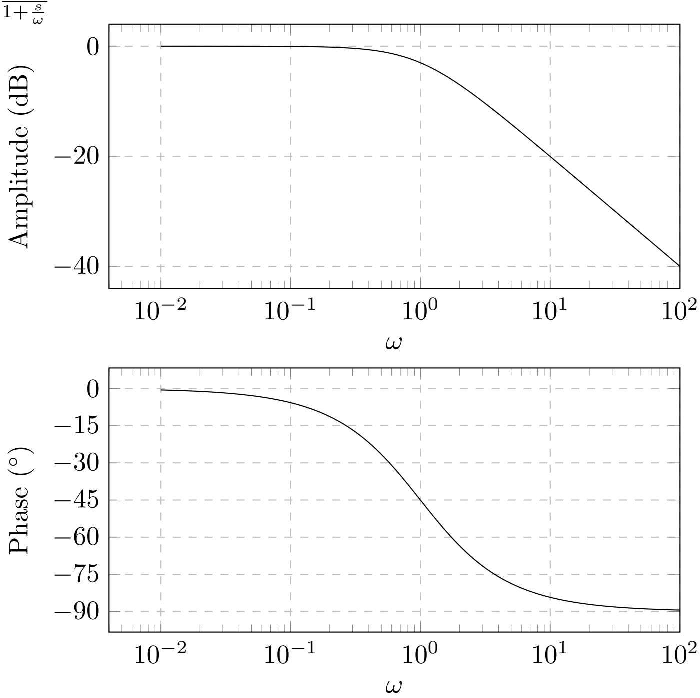
Standardelemente	Verstärkung $[\frac{dB}{dec}]$	Phase
Stabiler Pol	-20 bei ω_g	$-90°$ bei ω_g
Instabiler Pol	-20 bei ω_g	$+90°$ bei ω_g
Minimalphasige NullST	$+20$ bei ω_g	$+90°$ bei ω_g
Nichtminimalphasige NullST	$+20$ bei ω_g	$-90°$ bei ω_g
Delay um $\tau (\forall \omega)$	0	$-\frac{180}{\pi} \cdot \omega \cdot \tau°$

$\omega_g = \frac{1}{\tau}$: Cutoff-frequency (Eckfrequenz) immer bei $-3dB$

Graph bei $\omega = 1$

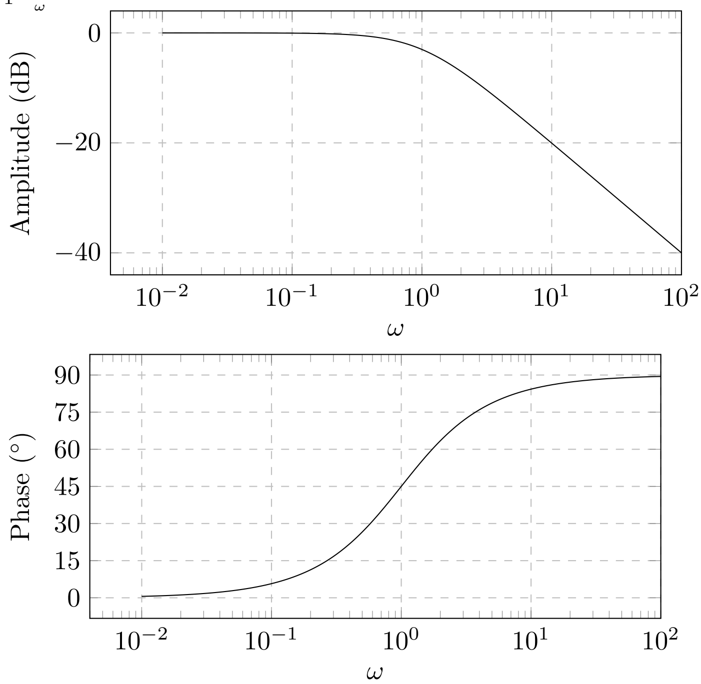
Stabiler Pol

$\frac{1}{1+\frac{s}{\omega}}$



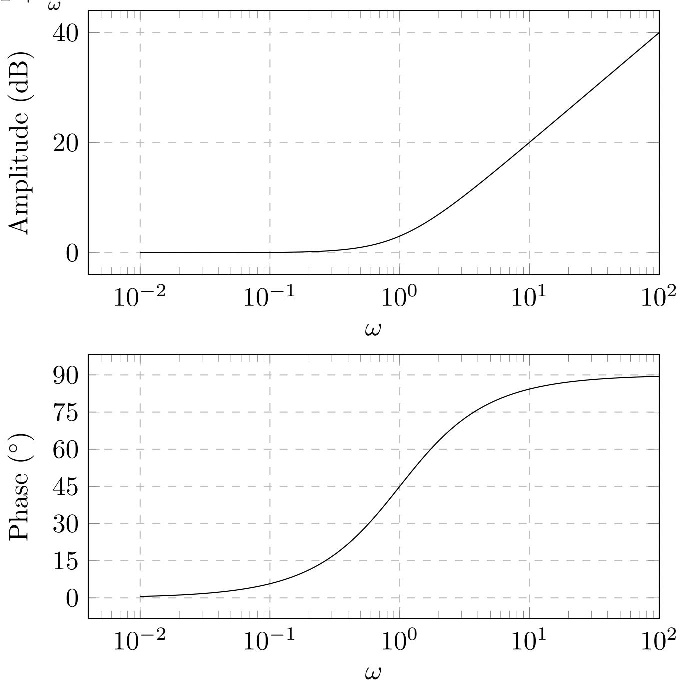
Instabiler Pol

$\frac{1}{1-\frac{s}{\omega}}$



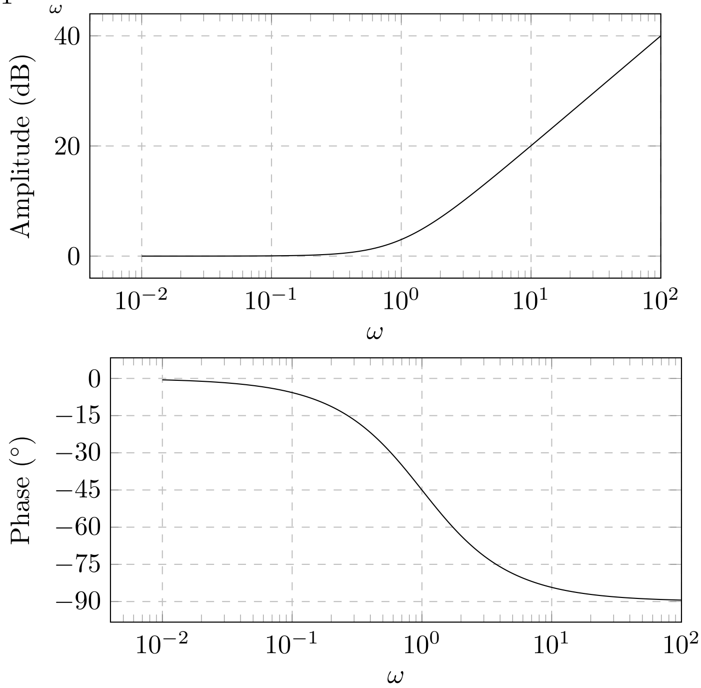
Minimalphasige Nullstelle

$1 + \frac{s}{\omega}$



Nichtminimalphasige Nullstelle

$1 - \frac{s}{\omega}$



Systemtyp k

Der **Systemtyp** k = Vielfachheit offener Integratoren ($\frac{1}{s^k}$)

$$\angle\Sigma(0) = \begin{cases} -k \cdot \frac{\pi}{2}, & sgn(\frac{b_0}{a_0}) > 0 \\ -\pi - k \cdot \frac{\pi}{2}, & sgn(\frac{b_0}{a_0}) < 0 \text{ (neg. stat. Gain)} \end{cases}$$

Relativer Grad $r = n - m$

Die Steigung des Magnitudenverlauf im Bode-Diagramm konvergiert asymptotisch zu:

$$\frac{\partial|\Sigma(j\omega)|_{dB}}{\partial \log(\omega)} = -r \cdot 20 \frac{dB}{\text{decade}}$$

Nyquist

$Asymptotisch-stabil \leftrightarrow n_c \overset{!}{=} \frac{n_0}{2} + n_+$

n_c: Anzahl Umrundungen um den kritischen Punkt (-1,0)
Positiv falls Umrundung gegen Uhrzeigersinn.
n_0: Anzahl Pole von $L(s)$ mit Realteil $= 0$
n_+: Anzahl Pole von $L(s)$ mit Realteil > 0

Frequenzbedingung des geschlossenen Regelkreises

ω_c =Durchtrittsfrequen $\omega_c = \begin{cases} \omega_c > \max\{10 \cdot \omega_d, 2 \cdot \omega_{\pi+}\} \\ \omega_c < \min\{\frac{1}{10} \cdot \omega_n, \frac{1}{10} \cdot \omega_2, \frac{1}{2} \cdot \omega_\tau, \frac{1}{2} \cdot \omega_{\zeta+}\} \end{cases}$

1. $\omega_2 \leftrightarrow |W_2(j\omega_2)| = 1$
2. $\omega_\tau = \frac{1}{\tau}$, mit $L_\tau(s) = C(s) \cdot P(s)e^{-\tau \cdot s}$. Wenn konservativ Faktor $\frac{1}{5}$
3. $\omega_{\zeta+}$ kleinster positiver Nullstelle. Wenn konservativ Faktor $\frac{1}{5}$
4. $\omega_n \leftrightarrow |N(j\omega_n)| = 0$
5. $\omega_{\pi+}$ grossten positiver Pol. Wenn konservativ Faktor 5
6. $\omega_d \leftrightarrow |D(j\omega_d)| = 0$

PID-Regler

$$C_{\text{PID}}(s) = k_p \cdot \overbrace{\left(\underbrace{\frac{T_d \cdot T_i \cdot s^2 + T_i \cdot s + 1}{T_i \cdot s}}_{\text{nicht kausal}} \right) \cdot \frac{1}{(\tau \cdot s + 1)^2}}^{\text{kausal}}$$

Ziegler-Nicholas Parameter

$$|k_p^* \cdot P(j\omega^*)| \overset{!}{=} 1 \quad \angle k_p^* \cdot P(j\omega^*) \overset{!}{=} -\pi \quad T^* = \frac{2\pi}{\omega^*}$$

Regler	k_p	T_i	T_d
P	$0.5 \cdot k_p^*$	$\infty \cdot T^*$	$0 \cdot T^*$
PI	$0.45 \cdot k_p^*$	$0.85 \cdot T^*$	$0 \cdot T^*$
PD	$0.55 \cdot k_p^*$	$\infty \cdot T^*$	$0.15 \cdot T^*$
PID	$0.6 \cdot k_p^*$	$0.5 \cdot T^*$	$0.125 \cdot T^*$

Åström-Hägglund Verfahren

$$\{k_p^*,\ T^*,\ |P(0)|,\ \mu_{\min}\} \to \{k_p,\ T_i,\ T_d\}$$

PI	$\mu_{\min} = 0.7$			$\mu_{\min} = 0.5$		
x	$\alpha_{0,x}$	$\alpha_{1,x}$	$\alpha_{2,x}$	$\alpha_{0,x}$	$\alpha_{1,x}$	$\alpha_{2,x}$
k_p/k_p^*	0.053	2.90	-2.60	0.13	1.90	-1.30
Ti/T^*	0.90	-4.40	2.70	0.90	-4.40	2.70
a	1.10	-0.0061	1.8	0.48	0.40	-0.17

PID	$\mu_{\min} = 0.7$			$\mu_{\min} = 0.5$		
x	$\alpha_{0,x}$	$\alpha_{1,x}$	$\alpha_{2,x}$	$\alpha_{0,x}$	$\alpha_{1,x}$	$\alpha_{2,x}$
k_p/k_p^*	0.33	-0.31	-1.00	0.72	-1.60	1.20
Ti/T^*	0.76	-1.60	-0.36	0.59	-1.30	0.38
T_d/T^*	0.17	-0.46	-2.10	0.15	-1.40	0.56
a	0.58	-1.3000	3.5	0.25	0.56	-1.20

$$\square = \square^* \cdot \alpha_{0,x} \cdot e^{\alpha_{1,x} \cdot \kappa + \alpha_{2,x} \cdot \kappa^2} \text{ mit } \kappa = \frac{1}{|P(0)| \cdot k_p^*}$$

Phasenreserve

γ	Verstärkungsreserve	Verstärkungsreserve zu $(-1+0j)$ bei $\angle L(j\omega) = -\pi$
φ	Phasenreserve	Phasenabstand zu $-\pi$ bei der Durchtrittsfrequenz ω_c
μ	kritische Abstand	Kleinste Distanz zwischen $(-1+0j)$ und $L(j\omega)$

Spezifikation der Sensitivität

Nominelle Regelgüte: $\|S(s) \cdot W_1(s)\|_\infty < 1 \Rightarrow |S(j\omega)| < |W_1^{-1}(j\omega)| \leftrightarrow |W_1(j\omega)| < |1 + L(j\omega)|$

Robuste Regelgüte: $|W_1(j\omega) \cdot S(j\omega)| + |W_2(j\omega) \cdot T(j\omega)| < 1 \leftrightarrow |W_1(j\omega)| + |W_2(j\omega) \cdot L(j\omega)| < |1 + L(j\omega)|$

Root Locus

Vorgehen

Ursprung der Asymptoten berechnen: $\sigma_a = \frac{1}{n-m}\left(\sum_{i=1}^{n} \mathrm{Re}(\pi_i) - \sum_{i=1}^{m} \mathrm{Re}(\zeta_i)\right)$, die Asymptoten verlassen den Punkt $(\sigma_a + j \cdot 0)$.
Winkel der Asymptoten bestimmen $\delta_i = \frac{\pi}{n-m} \cdot (2 \cdot (i-1) + 1)[\mathrm{rad}], \quad i = 1, \ldots, n-m$

Zugehörigkeitstest

Man kann testen ob ein Punkt $z \in \mathbb{C}$ auf der Wurzelortskurven liegt, indem man ihn in diese Gleichung einsetzt $(k_p > 0)$

$$\sum_{i=1}^{m} \angle(z - \zeta_i) - \sum_{i=1}^{n} \angle(z - \pi_i) \overset{!}{=} \begin{cases} -\pi \pm 2\pi \cdot k, k \in \mathbb{N} & k_p > 0 \\ 0 \mod 2\pi & k_p < 0 \end{cases}$$

Skizzierhilfen

- Root Locus ist Symmetrisch zur Re-Achse.
- Except the constant transfer function $P(s) = 0$ there is no other rational transfer function for which the positive and the negative root locus curve is identical.
- Treffen sich 2 Pole, dann drehen beide sich um $90°$ in der komplexen Ebene.
- A Pkt auf der Re-Achse kann sein Teil der RL nur wenn das # reelle Pole und Nullstelle auf sein rechts ist ungerade.
- $r = n - m$ Pole divergen entlang gerader Asymptoten $\to \infty$.
- Consider an open loop function $L(s) = k \cdot \frac{N(s)}{D(s)}$ with $k > 0$. If the degree of $N(s)$ and $D(S)$ are at most 1, then the root locus curve lies only on the real axis.

Z-Transform

$X(z) = \mathbb{Z}\{x(k)\} = \sum_{k=0}^{\infty} z^{-k} \cdot x(k) \leftrightarrow z = e^{sT_s}$

Emulation

$$\begin{aligned} z &= e^{sT_s} && \approx 1 + sT_s && \Rightarrow s \approx \frac{z-1}{T_s} && \text{Euler Forward} \\ z &= \frac{1}{e^{-sT_s}} && \approx \frac{1}{1 - sT_s} && \Rightarrow s \approx \frac{z-1}{zT_s} && \text{Euler Backward} \\ z &= \frac{e^{sT_s/2}}{e^{-sT_s/2}} && \approx \frac{1 + sT_s/2}{1 - sT_s/2} && \Rightarrow s \approx \frac{2(z-1)}{T_s(z+1)} && \text{Tustin Emulation} \end{aligned}$$

Hurwitz Stabilitätskriterium

$a_n \cdot s^n + a_{n-1} \cdot s^{n-1} + \cdots + a_1 \cdot s + a_0, \quad a_n > 0$ Stabil wenn Koeffizienten a_i bekannt. Falls alle führenden Hauptminoren der Hurwitzmatrix

$$H_1 = a_{n-1},\, H_2 = \begin{vmatrix} a_{n-1} & a_n \\ a_{n-3} & a_{n-2} \end{vmatrix},\, H_3 = \begin{vmatrix} a_{n-1} & a_n & 0 \\ a_{n-3} & a_{n-2} & a_{n-1} \\ a_{n-5} & a_{n-4} & a_{n-3} \end{vmatrix}$$

usw
positive sind, dann sind alle NST in der linken komplexen Halbebene.

MIMO/RGA

RGA $\begin{bmatrix} \frac{P_{11}P_{22}}{P_{11}P_{22}-P_{12}P_{21}} & \frac{-P_{12}P_{21}}{P_{22}P_{11}-P_{21}P_{12}} \\ \frac{-P_{12}P_{21}}{P_{22}P_{11}-P_{21}P_{12}} & \frac{P_{11}P_{22}}{P_{11}P_{22}-P_{12}P_{21}} \end{bmatrix}$

Singulärwerte

Lineare Abbildung mit: $\sigma_{\min}(M) \leq \frac{||y||}{||u||} \leq \sigma_{\max}(M)$ wobei $||.||$ die euklische Norm ist und

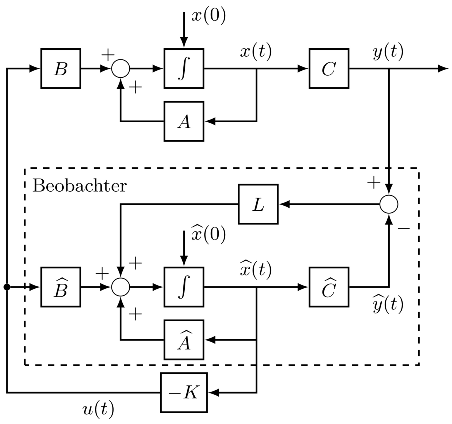
$$\sigma_i(M) = \sqrt{\lambda_i(\overline{M}^T \cdot M)} > 0,$$

Wichtig: die Eigenwert von $\overline{M}^T \cdot M$.
$\overline{M}^T$ bedeutet komplexe konj. des Elementes der Matrix.

LQR

Linear: da das System linear ist: $\frac{d}{dt}x(t) = A \cdot x(t) + B \cdot u(t),\ x(t) \in \mathbb{R}^n,\ u(t) \in \mathbb{R}^m$ **Quadratic:** Definition einer *quadratischen* Kostenfunktion J: $J(u(t)) = \int_0^\infty \Big(x(u(t))^T \cdot Q \cdot x(u(t)) + u(t)^T \cdot R \cdot u(t)\Big)dt$ **Lsg**: $u^*(t) = -K \cdot x(t),$ wobei $K = R^{-1} \cdot B^T \cdot \Phi$ **Ricatti Gleichung:** $\Phi \cdot B \cdot R^{-1} \cdot B^T \cdot \Phi - \Phi \cdot A - A^T \cdot \Phi - Q = 0$

LQG



$u(t) = -K \cdot \widehat{x}(t)$

More Laplace transform

$\{f(t)\}$	$f(t)$
$1/s$	1
$1/s^2$	t
$1/s^n$	$t^{n-1}/(n-1)!$
$1/\sqrt{s}$	$1/\sqrt{\pi t}$
$1/s^{3/2}$	$2\sqrt{t/\pi}$
$1/s^k$	$t^{k-1}/\Gamma(k)$
$\frac{1}{s-a}$	e^{at}
$\frac{1}{(s-a)^2}$	te^{at}
$\frac{1}{(s-a)^n}$	$\frac{1}{(n-1)!}t^{n-1}e^{at}$
$\frac{1}{(s-a)^k}$	$\frac{1}{\Gamma(k)}t^{k-1}e^{at}$
$\frac{\omega}{s^2+\omega^2}$	$\sin\omega t$
$\frac{a}{s^2-a^2}$	$\sinh at$
$\frac{\omega}{(s-a)^2+\omega^2}$	$e^{at}\sin\omega t$
$\frac{\omega}{(s-a)^2-\omega^2}$	$e^{at}\sinh\omega t$
$\frac{s}{s^2+\omega^2}$	$\cos\omega t$
$\frac{s}{s^2-a^2}$	$\cosh at$
$\frac{s-a}{(s-a)^2+\omega^2}$	$e^{at}\cos\omega t$
$\frac{s-a}{(s-a)^2-\omega^2}$	$e^{at}\cosh\omega t$
$\frac{\omega^2}{s(s^2+\omega^2)}$	$1-\cos\omega t$
$\frac{\omega^3}{s^2(s^2+\omega^2)}$	$\omega t-\sin\omega t$

$\{f(t)\}$	$f(t)$
e^{-as}/s	$u(t-a)$
e^{-as}	$\delta(t-a)$
$\frac{1}{\sqrt{s}}e^{-\omega/s}$	$\frac{1}{\sqrt{\pi t}}\cos 2\sqrt{\omega t}$
$e^{-k\sqrt{s}}$	$\frac{k}{2\sqrt{\pi t^3}}e^{-k^2/4t}$
$\frac{1}{(s-a)(s-b)}$	$\frac{1}{a-b}(e^{at}-e^{bt})$
$\frac{s}{(s-a)(s-b)}$	$\frac{1}{a-b}(ae^{at}-be^{at})$
$\frac{2\omega^3}{(s^2+\omega^2)^2}$	$\sin\omega t-\omega t\cos\omega t$
$\frac{2\omega s}{(s^2+\omega^2)^2}$	$t\sin\omega t$
$\frac{2\omega s^2}{(s^2+\omega^2)^2}$	$\sin\omega t+\omega t\cos\omega t$
$\frac{s^2}{(s^2+a^2)(s^2+b^2)}$	$\frac{1}{b^2-a^2}(\cos at-\cos bt)$
$\frac{4\omega^3}{s^4+4\omega^4}$	$\sin\omega t\cos\omega t-\cos\omega t\sinh\omega t$
$\frac{2\omega^2 s}{s^4+4\omega^4}$	$\sin\omega t\sinh\omega t$
$\frac{2\omega^3}{s^4-\omega^4}$	$\sinh\omega t-\sin\omega t$
$\frac{2\omega^2 s}{s^4-\omega^4}$	$\cosh\omega t-\cos\omega t$
$\ln\frac{s-a}{s-b}$	$\frac{1}{t}(e^{bt}-e^{at})$
$\ln\frac{s^2+\omega^2}{s^2}$	$\frac{2}{t}(1-\cos\omega t)$
$\ln\frac{s^2-\omega^2}{s^2}$	$\frac{2}{r}(1-\cosh\omega t)$

$k>0,\ n\in\mathbb{N},\ a\neq b,\ \gamma\approx 0.5772$

1 MATLAB Commands

Command	Description
`bode(SYS)`	Draws the Bode plot of the dynamic system SYS.
`[MAG,PHASE] = bode(SYS,W)` `[MAG,PHASE,W] = bode(SYS)`	Return the response magnitudes and phases in degrees (along with the frequency vector W if unspecified). No plot is drawn on the screen.
`W = logspace(-2,3,1e3)`	$10^{-2} < w < 10^3$ mit 1000 log-Werten
`nyquist(SYS)`	Draws the Nyquist plot of the dynamic system SYS.
`[RE,IM] = nyquist(SYS,W)` `[RE,IM,W] = nyquist(SYS)`	Return the real parts RE and imaginary parts IM of the frequency response (along with the frequency vector W if unspecified).
`sys = ss(A,B,C,D)`	Creates an object SYS representing the continuous-time state-space model
`(E =) [V,D] = eig(A)`	Produces a diag matrix D of eigenvalues and a matrix V whose columns are eigenvectors so that A*V = V*D. (Column vector E containing the Eigval of a matrix A.)
`co = ctrb(A,B) (= ctrb(SYS))`	Returns the controllability matrix $[BABA^2B...]$.
`ob = obsv(A,C) (= obsv(SYS))`	Returns the observability matrix $[C; CA; CA^2...]$
`s = tf('s')`	Specifies the transfer function H(s) = s (Laplace variable).
`SYS = tf(NUM,DEN, Ts, 'InputDelay', T)`	Creates a continuous-time transfer function SYS with numerator NUM and denominator DEN and optinal time delay T. (For discrete-time models add a sample time T_s)
`P = tf(sys)`	Converts any dynamic system SYS to the transfer function representation.
`MSYS = minreal(SYS)`	Produces, for a given LTI model SYS, an equivalent model MSYS where all cancelling pole/zero pairs or non minimal state dynamics are eliminated. For state-space models, minreal produces a minimal realization MSYS of SYS where all uncontrollable or unobservable modes have been removed.
`X = fminsearch(FUN,X0)`	Starts at X0 and attempts to find a local minimizer X of the function FUN. FUN is a function handle. FUN accepts input X and returns a scalar function value F evaluated at X. X0 can be a scalar, vector or matrix.
`P = pole(SYS))`	Returns poles P of the dynamic system SYS as a column vector. For state-space models, the poles are the eigenvalues of the A matrix. (Bei MIMO System die Pole der SISO-Elemente)
`[Z,G] = zero(SYS)`	Computes the zeros Z and gain G of the single-input, single-output dynamic system SYS.
`Z = tzero(SYS,TOL)`	Computes invariant zeros of the dynamic system SYS. For state-space models with matrices A,B,C,D,E (= I), the invariant zeros are the complex values s for which the rank of the matrix $\begin{bmatrix} A - sE & B \\ C & D \end{bmatrix}$ drops below its normal value. For minimal realizations, this coincides with the transmission zeros of SYS (values of s for which its transfer function drops rank).
`Ydb = mag2db(Y)`	Converts magnitude data Y into dB values. (db2mag analog)
`[NUM,DEN] = tfdata(SYS)`	Returns the num. and denom. of the transfer function SYS.
`[Z,P,K] = tf2zp(NUM,DEN)`	Finds the zeros, poles, and gains from a transferfunction in the form of $H(s) = K \cdot \frac{(s-z1)(s-z2)\dots(s-zn)}{(s-p1)(s-p2)\dots(s-pn)}$
`[Z,P,K] = zpkdata(SYS)`	Returns the zeros, poles, and gain for each I/O channel of the dynamic system SYS.
`K = dcgain(SYS)`	Computes the steady-state (D.C. or low frequency) gain of the dynamic system SYS $\big(P(j \cdot 0)\big)$
`eye(M)/ eye(M,N)/ eye(size(A))`	M-by-M/M-by-N/siz(A) matrix with 1's on the diagonal and zeros elsewhere.
`zeros(M)/ zeros(M,N)/ zeros(size(A))`	M-by-M/M-by-N/size(A) matrix of zeros.
`rga = P.*inv(P')`	MATLAB code to compute the RGA matrix of P
`bodemag(SYS)`	Plots the magnitude of the frequency response of the linear system SYS (useful for RGA/**Bode plot without the phase diagram**).
`sigma(SYS)`	Produces a singular value (SV) plot of the frequency response of the dynamic system SYS.
`[U,S,V] = svd(X)`	Produces a diagonal matrix S, of the same dimension as X and with nonnegative diagonal elements in decreasing order, and unitary matrices U and V so that $X = U \cdot S \cdot V^\top$.
`FRESP = evalfr(SYS,X)`	Evaluates the transfer function of the continuous- or discrete-time linear model SYS at the complex number S=X or Z=X. $\mathbf{X} = \mathbf{j}$**·omega** (Eval System, then plug it into svd)
`SimOut = sim('MODEL', PARAMETERS)`	Simulates your Simulink model, where 'PARAMETERS' represents a list of parameter name-value pairs.
`L = series(C,P)`	Connects the input/ouput models C and P in series.
`M = feedback(M1,M2)`	$(M1, M2) = (1, L) \Rightarrow S(s)$ and $(M1, M2) = (L, 1) \Rightarrow T(s)$. Computes a closed-loop model M (assumes negative feedback: for positive add ",+1")
$\mu_{\min} =$ `min(abs(bode(1 + L)))`	Computes the minimum return difference of a given open loop gain L
`[Gm,Pm,Wcg,Wcp] = margin(SYS)`	Computes the gain margin Gm, the phase margin Pm, and the associated frequencies Wcg and Wcp, for the SISO open-loop model SYS. The gain margin Gm is defined as 1/G where G is the gain at the -180 phase crossing. The phase margin Pm is in degrees. $\mathbf{k_p^*} = \mathbf{Gm}$, $\mathbf{T^*} = \frac{\mathbf{2\pi}}{\mathbf{Wcg}}$
`margin(SYS)`	Creates a Bode plot of the open loop and marks the gain and phase margins in the plot.
`B = squeeze(A)`	Returns an array B with the same elements as A but with all the singleton dimensions removed.
`SYSD = c2d(SYSC,TS,METHOD)`	Computes a discrete-time model SYSD with sample time TS that approximates the continuous-time model SYSC (method = zoh, foh, impulse, tustin,...)
`SYSC = d2c(SYSD,METHOD)`	Computes a continuous-time model SYSC that approximates the discrete-time model SYSD. (method = as above)
`[K,S,CLP] = lqr(SYS,Q,R) = lqr(A,B,Q,R)`	Calculates the optimal gain matrix K for the continuous or discrete state-space model SYS. lqr also returns the solution S of the associated algebraic Riccati equation and the closed-loop poles `CLP = eig(A-B*K)`.
`Ki_lqri = -K_tilde(:,n+1:end)`	Extraction of K_I from $\tilde{K}$