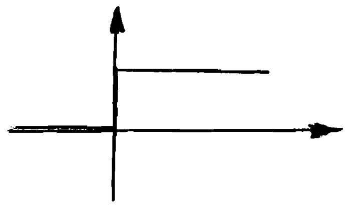
Problem I

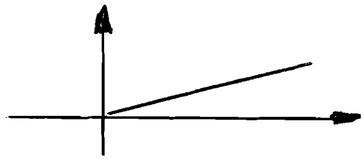
a) signals of control technique

1. step



2. (dirac) impulse

3. ramp function



b) weighting function = answer / response of a system on a (dirac) impulse as input

c) eigenvalue of a system λ_i

$$\Rightarrow \det(\lambda_i I - A) \overset{!}{=} 0$$

pole of a transfer function

e.g. $G(s) = \dfrac{K}{T_1 s + 1}$ $\Rightarrow$ pole: $s = -\dfrac{1}{T_1}$

SISO - system:
A pole is a solution of a characteristic equation.
Each pole is an eigenvalue, but not each eigenvalue is a pole.

d) PDT2 - System

Differential equation

$\Rightarrow T_2 \ddot{y} + T_1 \dot{y} + y = K \cdot (u + T_D \dot{u})$

Transfer function

$\Rightarrow T_2 s^2 y + T_1 s y + y = K (u + T_D s u)$

$\Leftrightarrow (T_2 s^2 + T_1 s + 1) y = K (1 + T_D s) u$

$$\Rightarrow \quad G(s) = \frac{Y(s)}{U(s)} = \frac{K \cdot (1 + T_D s)}{T_2 s^2 + T_1 s + 1}$$

e) MIMO - System

i) $\dot{x} = A x + B u$

$y = C x + D u$

ii) Transfer function $\qquad X(s) = \begin{pmatrix} X_1(s) \\ \vdots \\ X_n(s) \end{pmatrix}$

$$s X(s) = A \cdot X(s) + B \cdot U(s)$$

$\Leftrightarrow (sI - A) X(s) = B \cdot U(s)$

$\Leftrightarrow \quad X(s) = (sI - A)^{-1} B \cdot U(s)$

$\Rightarrow \quad Y(s) = C \left[(sI - A)^{-1} B + D \right] U(s)$

iii) eigenvalues and eigenvectors

EV λ_i $\qquad\qquad$ EV v_i

$\det(\lambda_i I - A) \overset{!}{=} 0 \qquad\qquad (\lambda_i I - A) v_i \overset{!}{=} 0$

Problem 2

a) PIT3 - behavior

differential equation PIT3 - system

$$\Rightarrow T_3 \dddot{y} + T_2 \ddot{y} + T_1 \dot{y} + y = K \cdot \left[u + \frac{1}{T_I} \int_0^t u(\tau) d\tau \right]$$

tranfer function

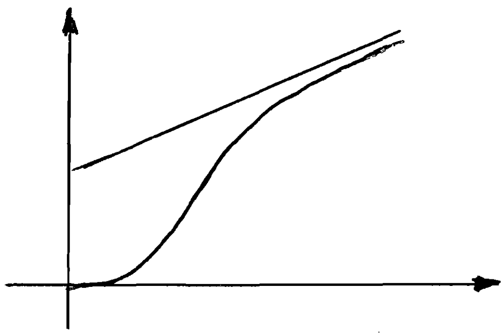
1. Laplace transformation

$$\Rightarrow T_3 s^3 y + T_2 s^2 y + T_1 s y + y = K \cdot \left[u + \frac{1}{T_I} \cdot \frac{1}{s} u \right]$$

$$\Leftrightarrow (T_3 s^3 + T_2 s^2 + T_1 s + 1) y = \left(K + \frac{K}{T_I s} \right) u$$

2. transfer function

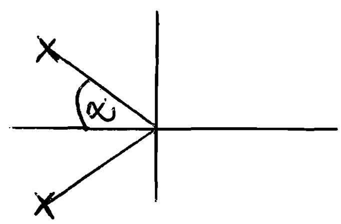
$$G(s) = \frac{Y(s)}{U(s)}$$



$$\Rightarrow G(s) = \frac{K + \frac{K}{T_I s}}{T_3 s^3 + T_2 s^2 + T_1 s + 1}$$

b) damping

$$D = \cos\left(\operatorname{atan} \frac{\operatorname{Im}\{\lambda_i\}}{\operatorname{Re}\{\lambda_i\}} \right)$$



oscillation between

$$0 \leq D < 1$$

c) occurence of the frequences in the signal

d) Laplace transformation

$$\mathcal{L}\{f(t)\} = \int_0^\infty f(t)\, e^{-st}\, dt$$

Dirac - Impulse

$$\delta(t) = \frac{1}{\alpha}\left[1(t) - 1(t-\alpha)\right] \quad ; \quad \alpha \to 0$$

$$\mathcal{L}\{\delta(t)\} = \int_{-0}^{\infty} \delta(t)\, e^{-st}\, dt$$

Dirac - impulse from $[-0 \,;\, +0]$

$$= \int_{-0}^{+0} \delta(t)\, \cancelto{1}{e^{-st}}\, dt + \int_{+0}^{\infty} \cancelto{0}{\delta(t)}\, e^{-st}\, dt$$

$$= \int_{-0}^{+0} \delta(t)\, dt$$

$$= \underline{\underline{1}} \qquad \boxed{\mathcal{L}\{\delta(t)\} = 1}$$

e) PIT1 - transfer function

$$G_S(s) = K_1 \frac{1 + \frac{1}{T_{I_1} s}}{1 + T_1 s}$$

PI transfer function

$$G_R(s) = K_2 \left[1 + \frac{1}{T_{I_2} s}\right]$$

e) disturbance transfer function

$$G_Z(s) = \frac{N_R\, N_S}{N_R\, N_S + Z_R Z_S} = \frac{G_S}{1 + G_R G_S} = \frac{G_S}{1 + G_0}$$

$$\Rightarrow \; G_Z(s) = \frac{T_1\, s + 1}{T_{I_1} s \left[(1 + T_1 s) + \left(1 + \frac{1}{T_{I_1} s}\right) K_2 \left(1 + \frac{1}{T_{I_S} s}\right) \right]}$$

guidance transfer function

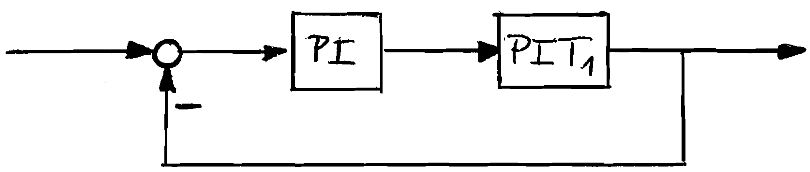
$$\Rightarrow \; G_W(s) = \frac{Z_R\, Z_S}{N_S N_R + Z_S Z_R} = \frac{G_R\, G_S}{1 + G_R G_S} = \frac{G_0}{1 + G_0}$$

$$= \frac{K_2 \left(1 + \frac{1}{T_{I_2} s}\right) \left(1 + \frac{1}{T_{I1} s}\right)}{(1 + T_1 s) + K_2 \left(1 + \frac{1}{T_{I_2} s}\right) \left(1 + \frac{1}{T_{I1} s}\right)}$$

$\rightarrow$ The system is semi-stable.

(Pole with $s = 0$)

block diagram.



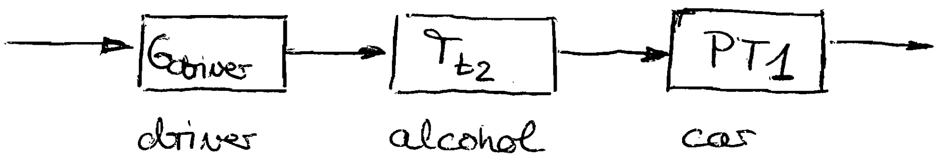
Problem 3

a)

$$G(s) = \frac{K_1}{T_1 s + 1} \qquad K_1 = 1 \quad T_1 = 1$$

$$\Rightarrow G(s) = \frac{1}{s+1}$$

$$G_{driver_1} = \frac{K_1}{1+T_1 s} e^{-T_{t_1} s} \qquad K_1 = 10 \quad T_1 = 1 \quad T_{t_1} = 0.6$$



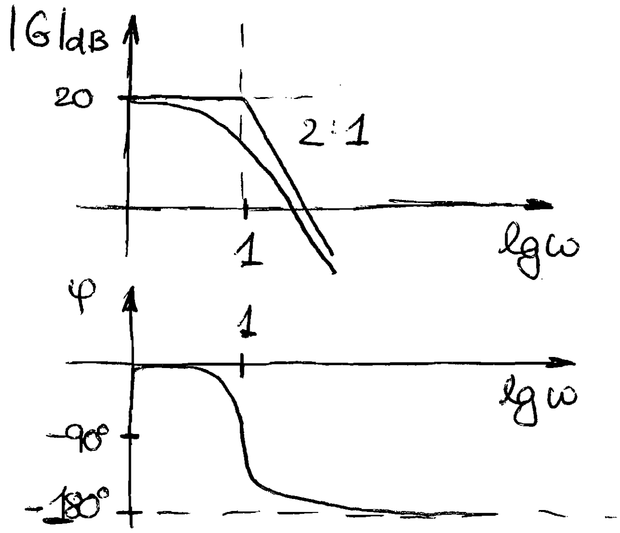
$$G_{driver_2} = \frac{K}{1+T_1 s} e^{-(T_{t_1}+T_{t_2})s} \qquad T_{t_2} = 1$$

$$= \frac{10}{1+s} e^{-1.6 s}$$

$$G_0(s) = \frac{1}{(1+s)(1+s)} e^{-1.6 s}$$

a)

Bode - Diagram



Stability:

Dead time,

because it causes a phase shift which causes a loss of stability

b)

$$10\ddot{y} + Ky = u(t)$$

$$\Rightarrow \ddot{y} + \frac{K}{10} y = \frac{u(t)}{10}$$

$$\dot{x} = \begin{bmatrix} \dot{y} \\ \ddot{y} \end{bmatrix}$$

$$A = \begin{bmatrix} 0 & 1 \\ -\frac{K}{10} & 0 \end{bmatrix}$$

$$\Rightarrow \begin{bmatrix} \dot{y} \\ \ddot{y} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -\frac{K}{10} & 0 \end{bmatrix} \begin{bmatrix} y \\ \dot{y} \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{1}{10} \end{bmatrix} u(t)$$

$$y = \begin{bmatrix} 1 & 0 \end{bmatrix}$$

Eigenvalues $\lambda_{1,2}$

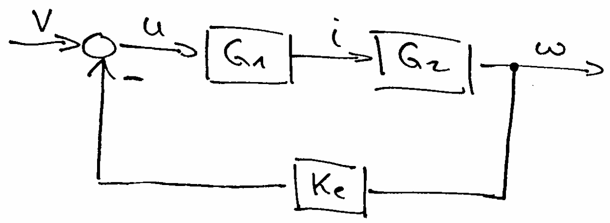
$$\det(\lambda_i I - A) \overset{!}{=} 0 \qquad \Rightarrow \qquad \lambda_{1,2} = \pm\sqrt{-\frac{K}{10}}$$

$$\Rightarrow \lambda^2 + \frac{K}{10} = 0 \qquad\qquad = \pm j\sqrt{\frac{K}{10}}$$

Because of $Re\{\lambda_i\}$ for $\lambda_{1,2} = 0$:

System is not asymptotically stable.

4 a)



$$u = V - K_e \cdot \omega$$

$$i = G_1 \cdot u = G_1 \cdot V - G_1 \cdot K_e \cdot \omega$$

$$\omega = G_2 \cdot i = G_2 \cdot G_1 \cdot V - G_2 \cdot G_1 \cdot K_e \cdot \omega \quad \Rightarrow [\text{rearranging}] \Rightarrow$$

$$\Rightarrow \quad \omega (1 + G_2 G_1 \cdot K_e) = G_2 G_1 \cdot V \quad \Rightarrow$$

$$\Rightarrow \quad \frac{\omega}{V} = G_{V\omega}(s) = \frac{G_1 G_2}{1 + G_1 G_2 K_e} = [\text{insertion}] =$$

$$= \frac{\dfrac{K_t}{(Ls+R)(Js+b)}}{1 + \dfrac{K_t \cdot K_e}{(Ls+R)(Js+b)}} = \frac{K_t}{(Ls+R)(Js+b) + K_t K_e}$$

b)

$$G_{vw}(s) = \frac{1}{(s+3)(s+2)+K_e} = \frac{1}{s^2+5s+6+K_e}$$

Characteristic equation:

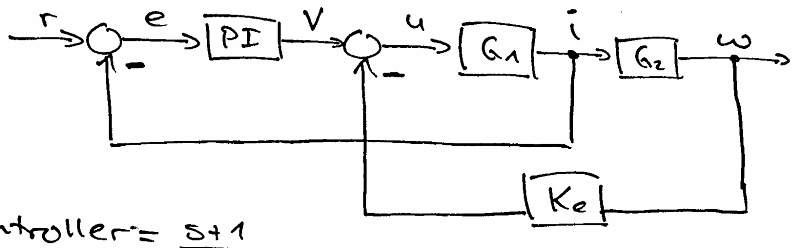
$$s^2+5s+6+K_e=0$$

$$s = -\frac{5}{2} \pm \sqrt{\frac{25}{4}-6-K_e} = -\frac{5}{2} \pm \frac{1}{2}\sqrt{1-4K_e}$$

$\Rightarrow$ Oscillations principally occur, when complex solutions are possible, i.e.

when $\underline{\underline{K_e > \frac{1}{4}}}$.

c)



PI-controller $= \frac{s+1}{s}$

$$e = r - i$$

$$V = \frac{s+1}{s} \cdot e = \frac{s+1}{s} \cdot r - \frac{s+1}{s} \cdot i$$

$$u = V - K_e \cdot \omega = \frac{s+1}{s} \cdot r - \frac{s+1}{s} \cdot i - K_e \cdot w$$

$$i = G_1 \cdot u = \frac{s+1}{s} \cdot G_1 \cdot r - \frac{s+1}{s} \cdot G_1 \cdot i - G_1 \cdot K_e \cdot w$$

[rearranging]:

$$i + \frac{s+1}{s} \cdot G_1 \cdot i = \frac{s+1}{s} \cdot G_1 \cdot r - G_1 \cdot K_e \cdot w \Rightarrow$$

$$i = \frac{\frac{s+1}{s} \cdot G_1 \cdot r - G_1 \cdot K_e \cdot w}{1 + \frac{s+1}{s} \cdot G_1} = \frac{(s+1) G_1 \cdot r - G_1 \cdot K_e \cdot s \cdot w}{s + G_1 s + G_1}$$

$$\omega = G_2 \cdot i = \frac{(s+1) G_1 G_2 r - G_1 G_2 K_e \cdot s \cdot w}{G_1 \cdot s + s + G_1} = [\text{rearranging}] \Rightarrow$$

$$\Rightarrow \omega = \frac{G_1 G_2 \cdot s + G_1 G_2}{s(G_1 + G_1 G_2 K_e + 1) + G_1} = \ldots$$

....c)

$$\omega = \frac{G_1 G_2 s \cdot r + G_1 G_2 r}{G_1 s + s + G_1} - \frac{G_1 G_2 K_e \cdot s}{G_1 s + s + G_1} \cdot \omega$$

$$\omega \left(1 + \frac{G_1 G_2 K_e \cdot s}{G_1 s + s + G_1} \right) = \frac{G_1 G_2 s + G_1 G_2}{G_1 s + s + G_1} \cdot r$$

$$\omega = \frac{G_1 G_2 s + G_1 G_2}{G_1 s + s + G_1 + G_1 G_2 K_e s} \cdot r = [\text{Insertion}]$$

$$= \frac{\dfrac{K_t \cdot s}{(Ls+R)(Js+b)} + \dfrac{K_t}{(Ls+R)(Js+b)}}{\dfrac{K_t \cdot s}{Ls+R} + s + \dfrac{K_t}{Ls+R} + \dfrac{K_t K_e \cdot s}{(Ls+R)(Js+b)}} =$$

$$= \frac{K_t \cdot s + K_t}{K_t \cdot s(Js+b) + s(Ls+R)(Js+b) + K_t(Js+b) + K_t K_e \cdot s} =$$

$$= \frac{s+1}{s(s+2) + s(s+3)(s+2) + 1(s+2) + K_e \cdot s} =$$

$$= \frac{s+1}{s^2 + 2s + s(s^2+5s+6) + s + 2 + K_e \cdot s} =$$

$$= \frac{s+1}{\cancel{s^3} + \cancel{5s^2} + \cancel{6s} + \cancel{s^2} + \cancel{2s} + \cancel{s} + 2 + \cancel{K_e \cdot s}} =$$

$$= \frac{s+1}{s^3 + 6s^2 + s(9+K_e) + 2}$$

d)

$$G(s) = \frac{s+1}{s^3 + 6s^2 + 10s + 2}$$

$\left\{ \text{Initial value theorem:} \quad \lim_{t \to 0^+} f(t) = \lim_{s \to \infty} s \cdot F(s) \right\}$

$$\lim_{s \to \infty} s \cdot G(s) \cdot \underbrace{\frac{1}{s}}_{\text{step input}} = \lim_{s \to \infty} \frac{s+1}{s^3 + 6s^2 + 10s + 2} = 0$$

$\left\{ \text{Final value theorem:} \quad \lim_{t \to \infty} f(t) = \lim_{s \to 0} s \cdot F(s) \right\}$

$$\lim_{s \to 0} s \cdot G(s) \cdot \underbrace{\frac{1}{s}}_{\text{step input}} = \lim_{s \to 0} \frac{s+1}{s^3 + 6s^2 + 10s + 2} = \frac{1}{2}$$

Gradients:

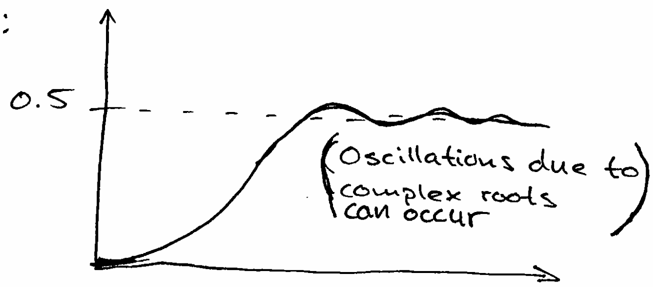
Initial value:

$$\lim_{s \to \infty} s \cdot G(s) \cdot \underbrace{s}_{\text{derivative}} \cdot \underbrace{\frac{1}{s}}_{\text{step input}} = \lim_{s \to \infty} \frac{s^2 + s}{s^3 + 6s^2 + 10s + 2} = 0$$

Final value:

$$\lim_{s \to 0} s \cdot G(s) \cdot s \cdot \frac{1}{s} = \lim_{s \to 0} \frac{s^2 + s}{s^3 + 6s^2 + 10s + 2} = 0$$

Step response:



Problem 5:

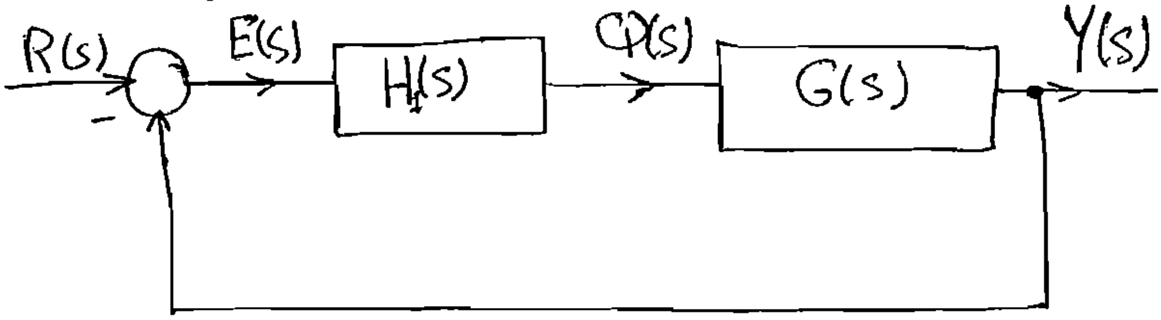
a) $\dot{y}(t) = \frac{1}{A} q(t)$ (1)

Laplace transfor of (1)

$$Y(s) = \frac{1}{A} \cdot \frac{1}{s} Q(s) \Rightarrow G(s) = \frac{Y(s)}{Q(s)} = \frac{1}{A \cdot s}$$

b) 1. PIT1-element: $H_1(s) = K \frac{\left(1 + \frac{1}{T_I s}\right)}{(1 + T_1 s)} = K \frac{\left(1 + \frac{1}{s}\right)}{(1+s)}$

⊛ Negative feedback:



Open-loop system: $H_1(s) \cdot G(s) = C_{o1}(s)$

$$C_{o1}(s) = \frac{K\left(1 + \frac{1}{s}\right)}{(1+s)} \cdot \frac{1}{As} = \frac{K\left(\frac{s+1}{s}\right)}{As(s+1)} = \frac{K\cancel{(s+1)}}{As^2\cancel{(s+1)}}$$

$$C_{o1}(s) = \frac{K}{As^2}$$

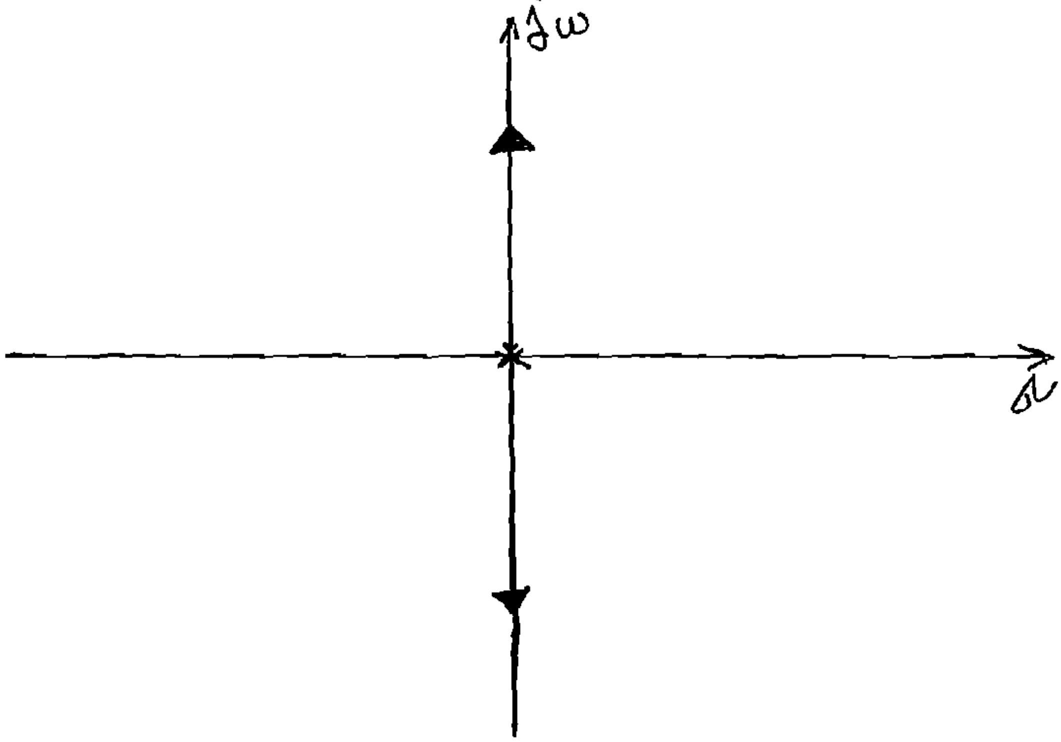
- Root locus of $C_{o1}(s)$

  *- poles: $P_{1,2} = 0 \Rightarrow n = 2$.

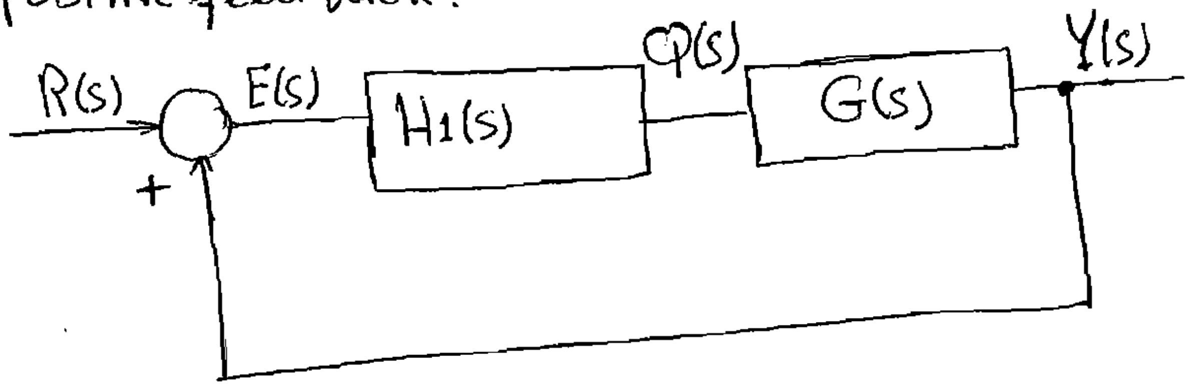
  *- there are no zeros $\Rightarrow m = 0$.

  *- $\varphi_r = \frac{(2r-1)\pi}{n-m} = \frac{(2r-1)\pi}{2}$; $r = 1, 2$

$$\varphi_r = \mp \frac{\pi}{2}$$



⊛ Positive feed back:



Open-loop system:

$$C_{o2}(s) = \frac{K(1+\frac{1}{s})}{(1+s)} \cdot \frac{1}{As} = \frac{K}{As^2}$$

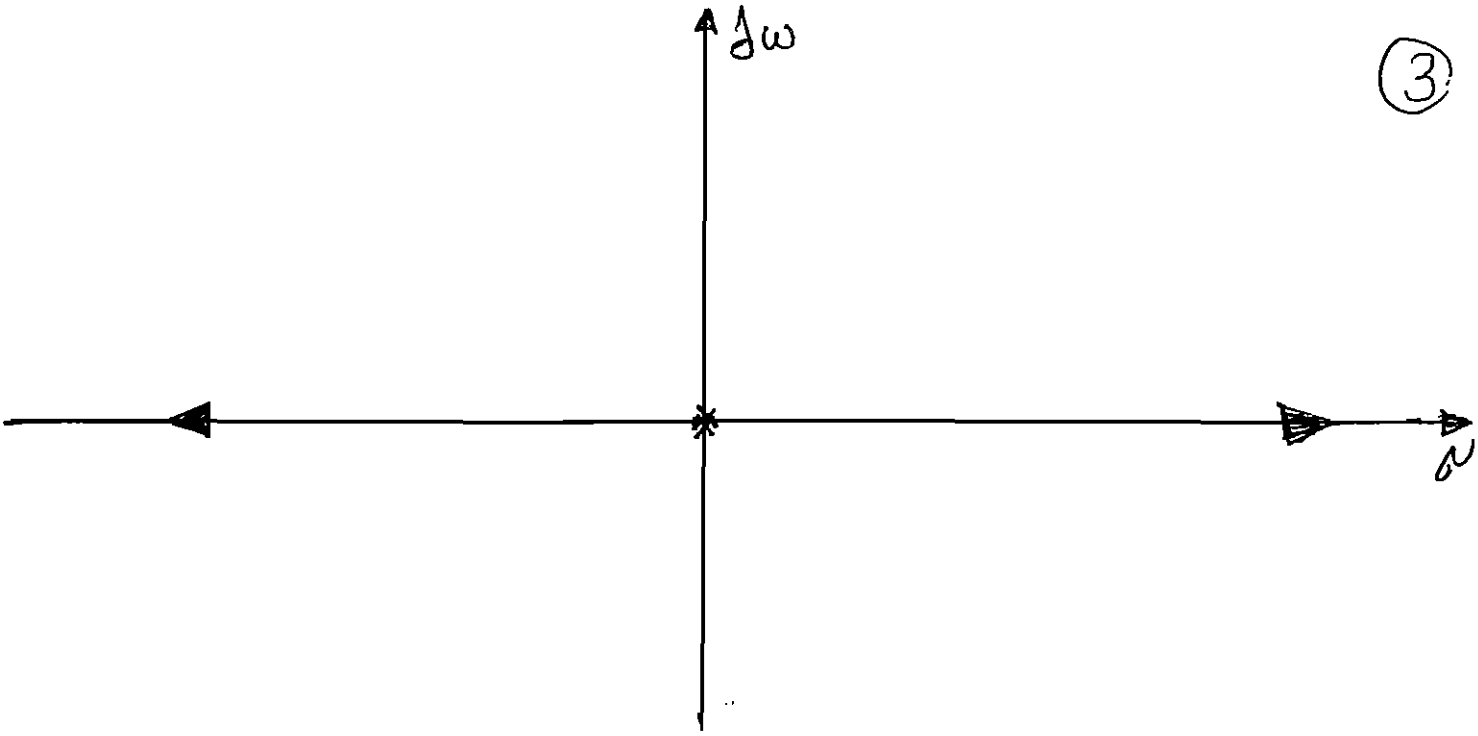
Root locus of $C_{o2}(s)$:

*- Poles: $P_{1,2} = 0 \Rightarrow n = 2$.

*- zeros: There are no zeros $\Rightarrow m = 0$.

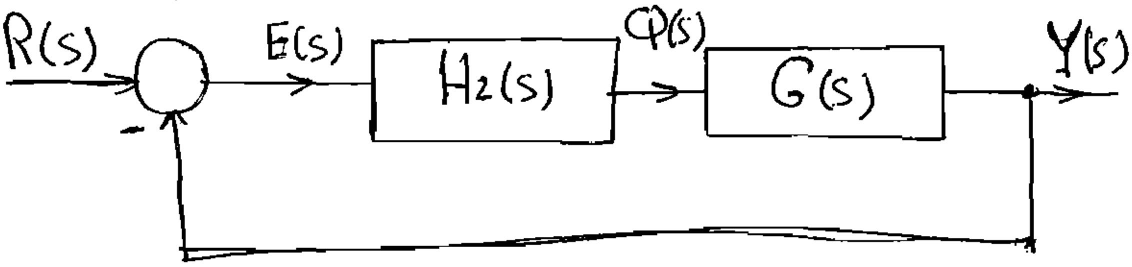
*- $\varphi_r = \frac{2r\pi}{n-m} = \frac{2r\pi}{2} = r\pi \quad , r = 1,2$

$\varphi_r = \mp\pi$



2. PDT₁ - element: $H_2(s) = K\frac{(1+T_D s)}{(1+T_1 s)}$ $K\frac{(1+2s)}{(1+s)}$

* Negative feedback:



Open-loop system is: $C_{o3} = H_2(s)\cdot G(s) = K\frac{(1+T_D S)}{(1+T_1 S)}\cdot\frac{1}{AS}$

$$C_{o3} = \frac{K(1+2s)}{As(1+s)} = \frac{K(1+2s)}{A(s^2+s)}$$

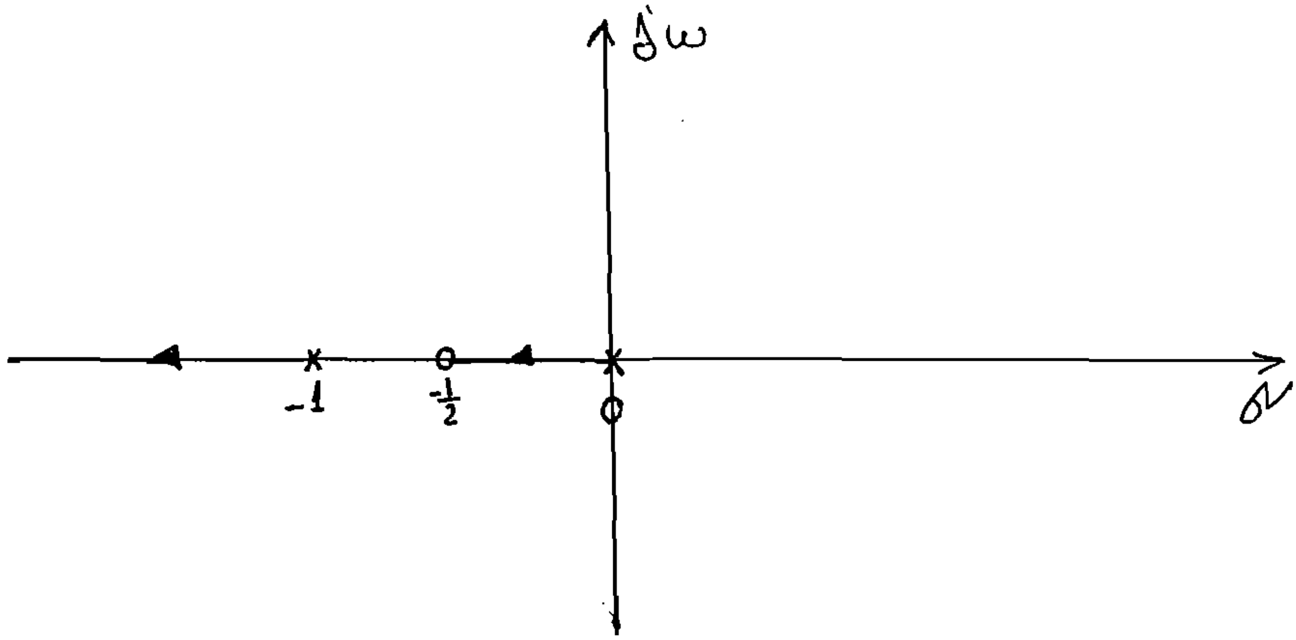
Root locus of C_{o3}:

*- Zeros: $z_1 = -1/2 \Rightarrow m = 1$.

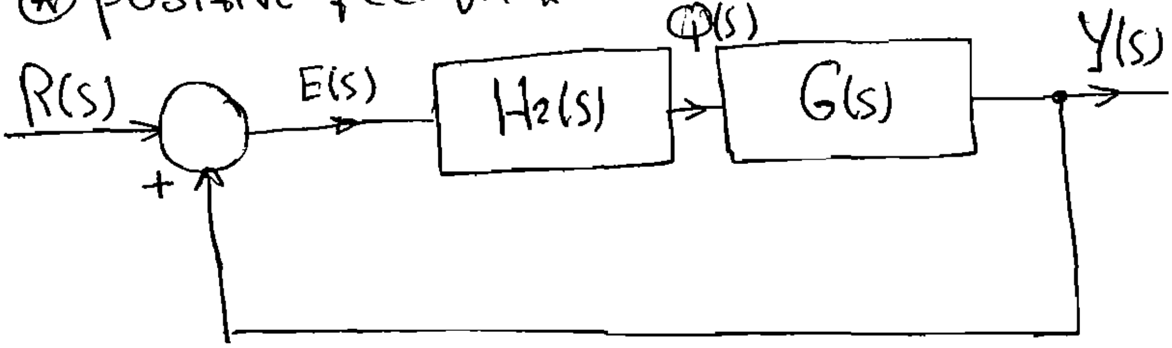
*- Poles: $AS(S+1) = 0 \Rightarrow P_1 = 0$ & $P_2 = -1 \Rightarrow n = 2$.

*- $\varphi_r = \frac{(2r-1)\pi}{n-m} = \frac{(2r-1)\pi}{2-1} = (2r-1)\pi$; $r = 1$

$\varphi_r = \pi$



⊛ positive feedback:



Open-loop system: $C_{o4} = H_2(s) \cdot G(s) = K\frac{(1+T_D s)}{(1+T_I s)} \cdot \frac{1}{As}$

$$C_{o4} = \frac{K(1+2s)}{A(s^2+s)}$$

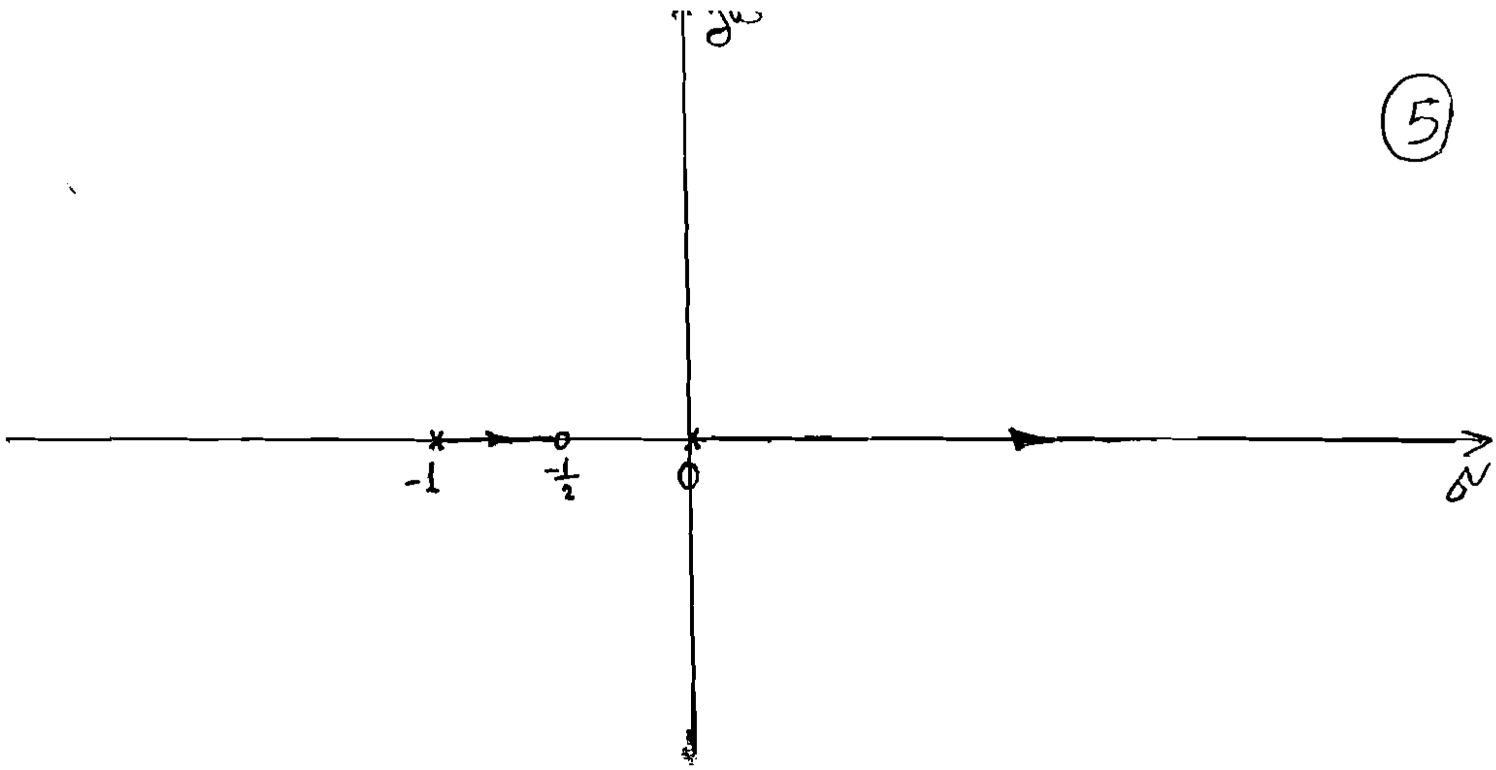
Root-locus of C_{o4}:

* - Zeros : $Z_1 = -1/2 \Rightarrow m=1$.

* poles : $s^2+s=0 \Rightarrow s(s+1)=0 \Rightarrow P_1=0$ & $P_2=-1 \Rightarrow n=2$.

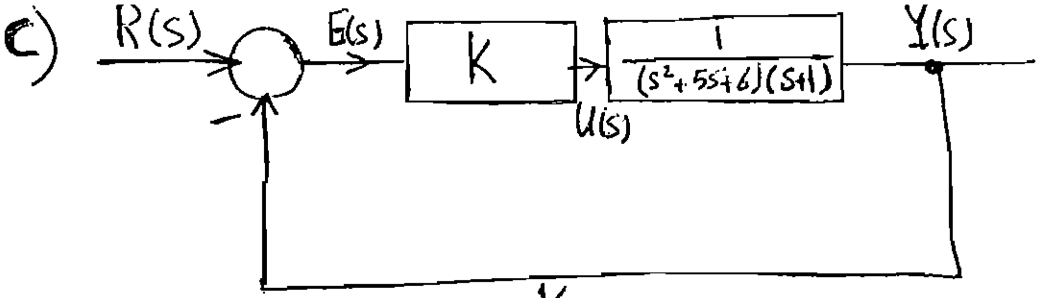
* $\varphi_r = \frac{2r\pi}{n-m} = 2r\pi$; $r=1 \Rightarrow \varphi_r = 2\pi$

5



The system can be asymptotic only with PDT₁-element and negative feedback for $\boxed{K > 0}$

c)



6

$$C(s) = \frac{\frac{K}{(s^2+5s+6)(s+1)}}{1+\frac{K}{(s^2+5s+6)(s+1)}}$$

$$C(s) = \frac{\frac{K}{\cancel{(s^2+5s+6)(s+1)}}}{\frac{(s^2+5s+6)(s+1)+K}{\cancel{(s^2+5s+6)(s+1)}}}$$

$$C(s) = \frac{K}{s^3+s^2+5s^2+6s+6+K+5s}$$

$$C(s) = \frac{K}{s^3+6s^2+11s+6+k}$$

Characteristic equation:

$$\left.\begin{aligned} s^3+6s^2+11s+6+K &= 0 \\ a_0s^3+a_1s^2+a_2s+a_3 &= 0 \end{aligned}\right\} \Rightarrow$$

$a_0 = 1$ & $a_1 = 6$ & $a_2 = 11$ & $a_3 = 6+K \Rightarrow \boxed{K > -6}$

$\Delta_1 = |a_1| = 1 > 0$

$$\Delta_2 = \begin{vmatrix} a_1 & a_3 \\ a_0 & a_2 \end{vmatrix} > 0 \Rightarrow \begin{vmatrix} 6 & 6+K \\ 1 & 11 \end{vmatrix} > 0$$

$66 - 6 - k > 0 \Rightarrow 60 - k > 0 \Rightarrow \boxed{K < 60}$

The system is stable for $\boxed{-6 < K < 60}$

d) Open-loop system:

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$$C(s) = \frac{K}{(s+1)(s+2)(s+3)} \quad ; K = 6$$

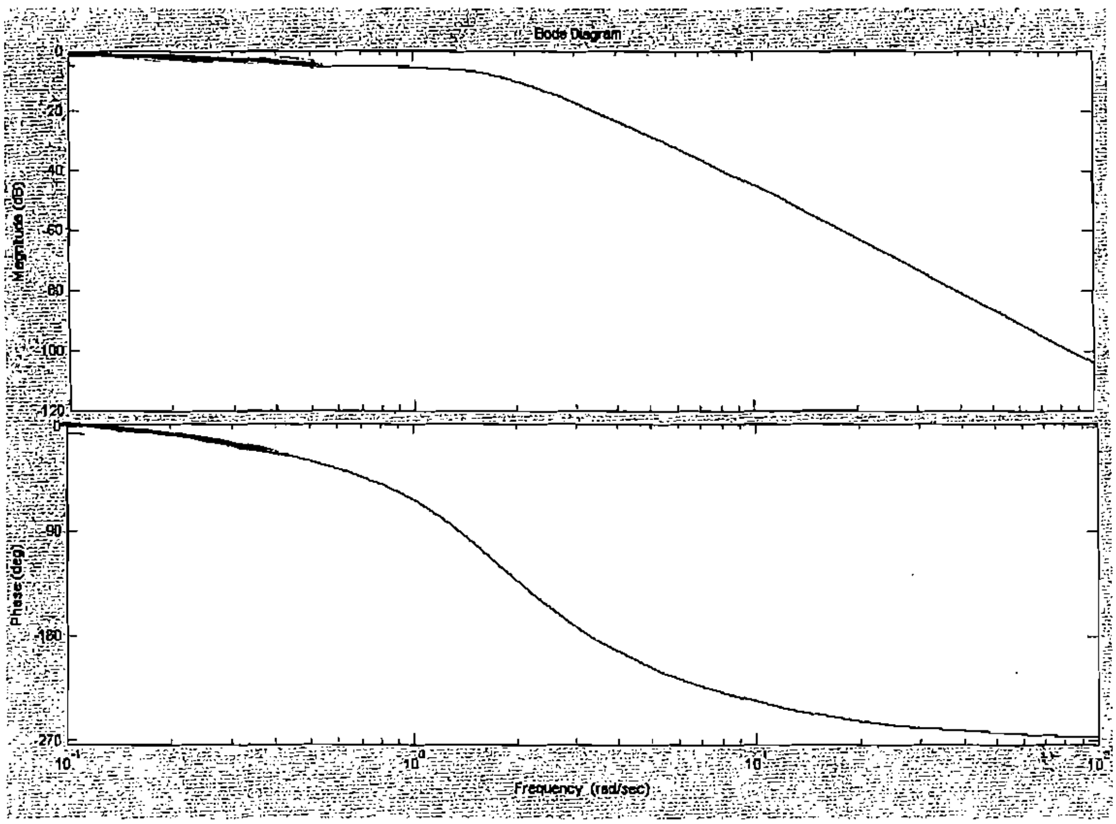
$$C(s) = \frac{6}{(s+1)(s+2)(s+3)}$$

No zeros & Poles: $P_1 = -1$, $P_2 = -2$, $P_3 = -3$.

$$C(s) = \frac{\cancel{6}}{\cancel{6}(1+\frac{s}{1})(1+\frac{s}{2})(1+\frac{s}{3})}$$

$$C(s) = \frac{1}{(1+\frac{s}{1})(1+\frac{s}{2})(1+\frac{s}{3})}$$

$\omega_{o1} = 1$ rad/sec & $\omega_{o2} = 2$ rad/sec & $\omega_{o3} = 3$ rad/sec



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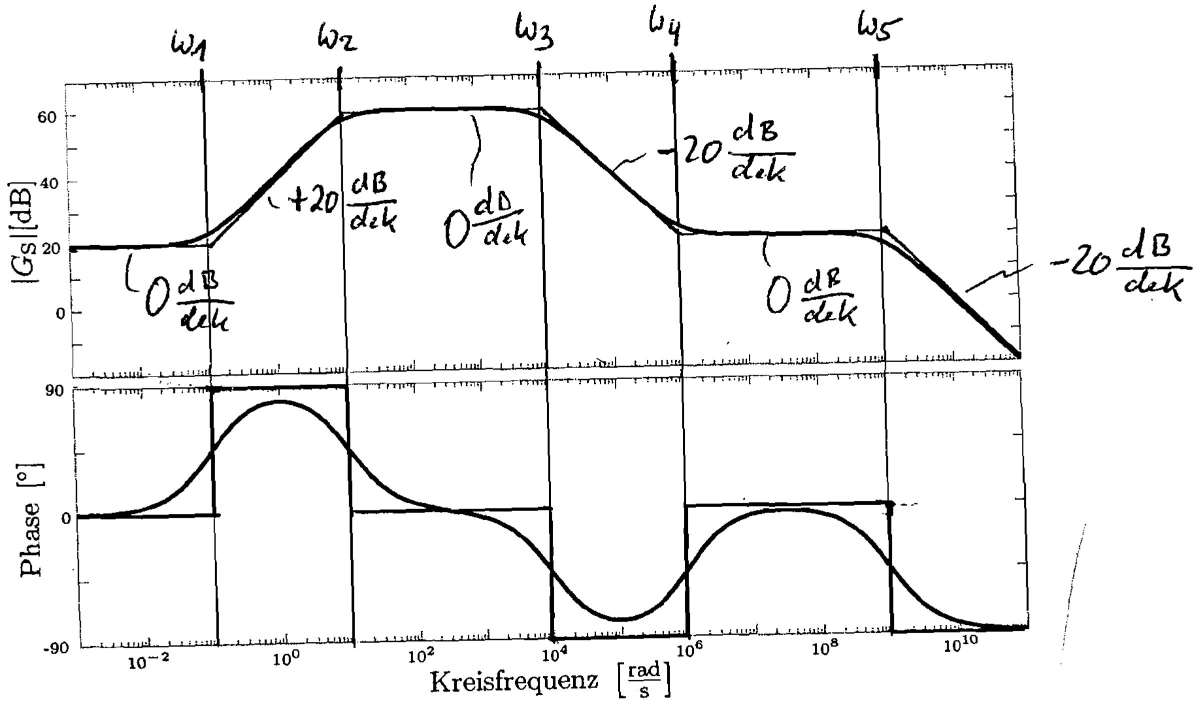
a)



b) $$G_S(s) = K_S \cdot \frac{\left(\frac{1}{\omega_1}s+1\right)\left(\frac{1}{\omega_4}s+1\right)}{\left(\frac{1}{\omega_2}s+1\right)\left(\frac{1}{\omega_3}s+1\right)\left(\frac{1}{\omega_5}s+1\right)}$$

$\underline{K_S = 20\,dB \mathrel{\hat{=}} 10}$

OR

$$G_S(s) = K_S \cdot \frac{(s+\omega_1)(s+\omega_4)}{(s+\omega_2)(s+\omega_3)(s+\omega_5)}, \quad K_S = 10 \cdot \frac{\omega_2\omega_3\omega_5}{\omega_1\omega_4}$$

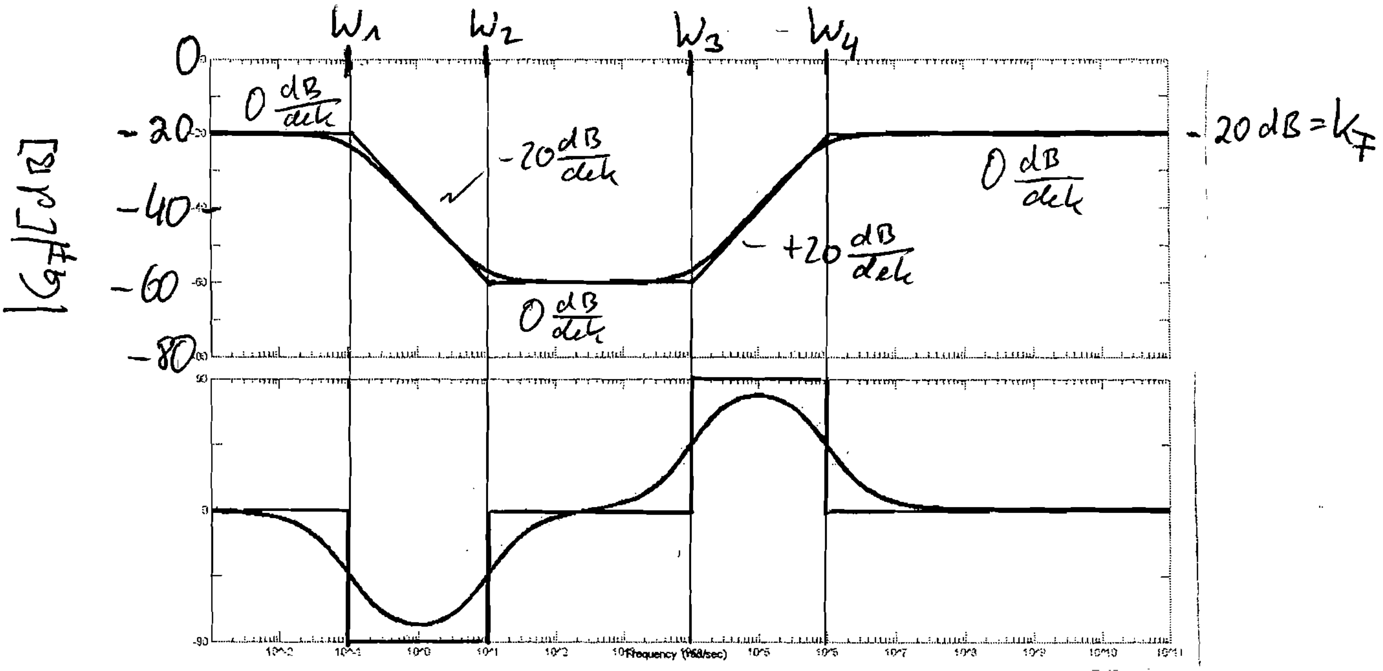
---

c) $$G_F = K_F \cdot \frac{\left(\frac{1}{\omega_2}s+1\right)\left(\frac{1}{\omega_3}s+1\right)}{\left(\frac{1}{\omega_1}s+1\right)\left(\frac{1}{\omega_4}s+1\right)}$$

$K_F = -20\,dB \mathrel{\hat{=}} 0.1$

Aufgabe 6

d)



e) Yes, because signals with $f \approx 50$ GHz are damped with -34 dB ($\hat{=}\ 0.02$)

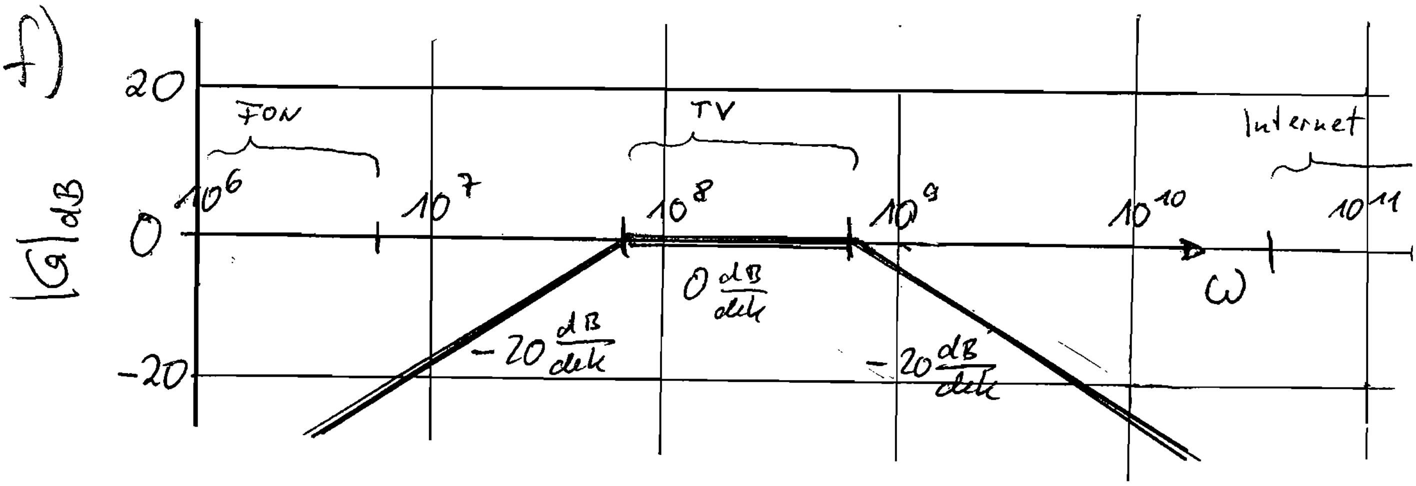
OR

Yes, because signals with $f \approx 10$ GHz are damped with -20 dB ($\hat{=}\ 0.1$)

10 GHz < 50 GHz (even more damped)

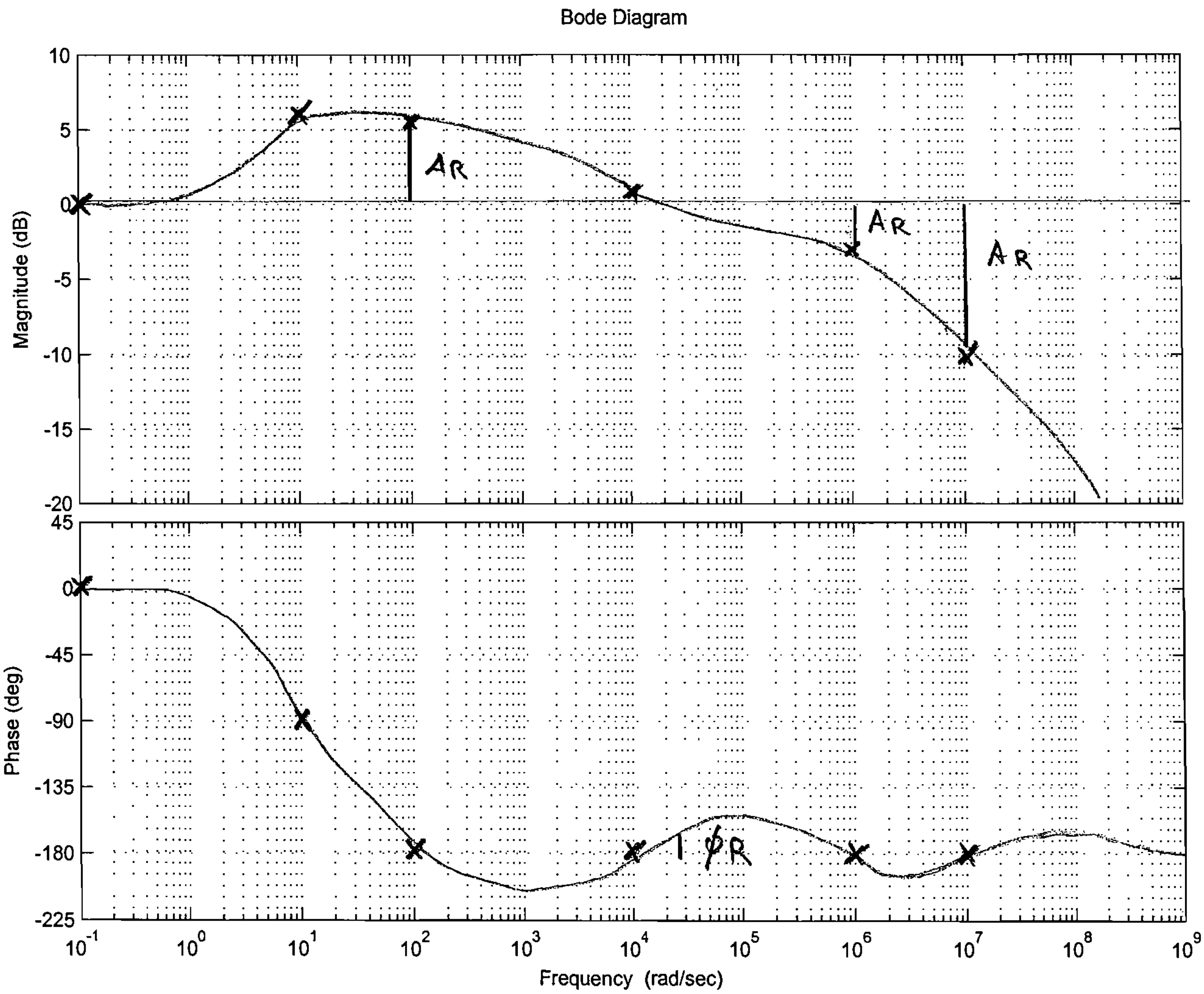
Aufgabe 6

f)



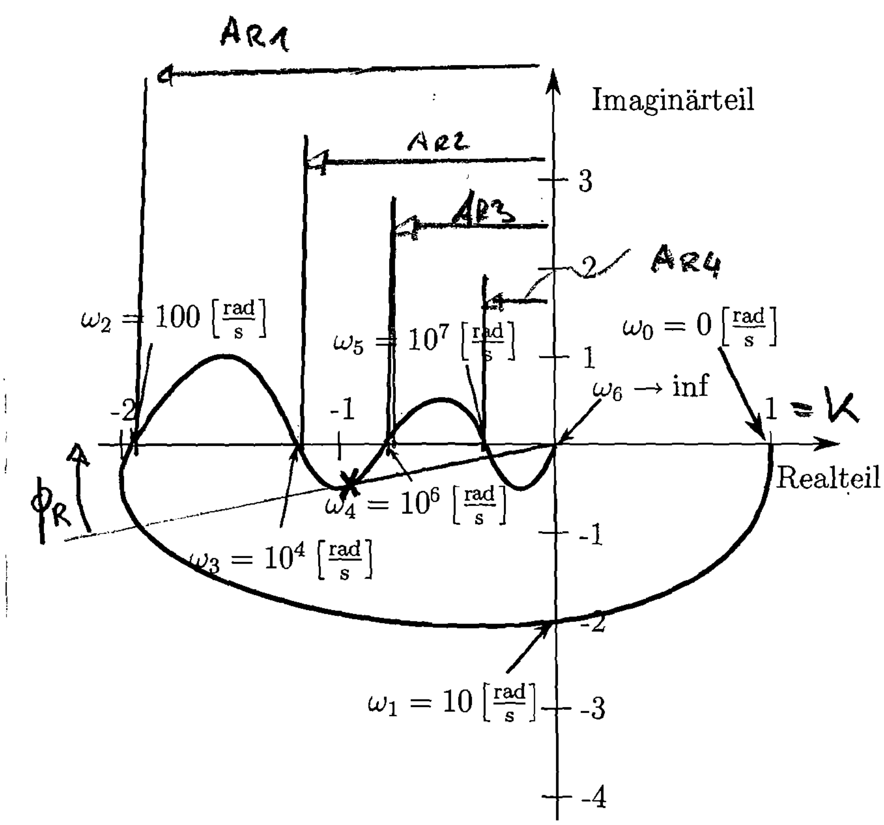
20
0
-20
$|G|_{dB}$
FON
TV
Internet
10^6
10^7
10^8
10^9
10^{10}
10^{11}
ω
$-20\frac{dB}{dek}$
$0\frac{dB}{dek}$
$-20\frac{dB}{dek}$

g)



Bode Diagram
Magnitude (dB)
Phase (deg)
Frequency (rad/sec)
A_R
A_R
A_R
ϕ_R

Aufgabe 6



h) Yes, it is stable; $(-1/0j)$ is on the left side of the curve (spez. Nyquist).

Stable for: $K < \frac{1}{A_{R1}}$ or

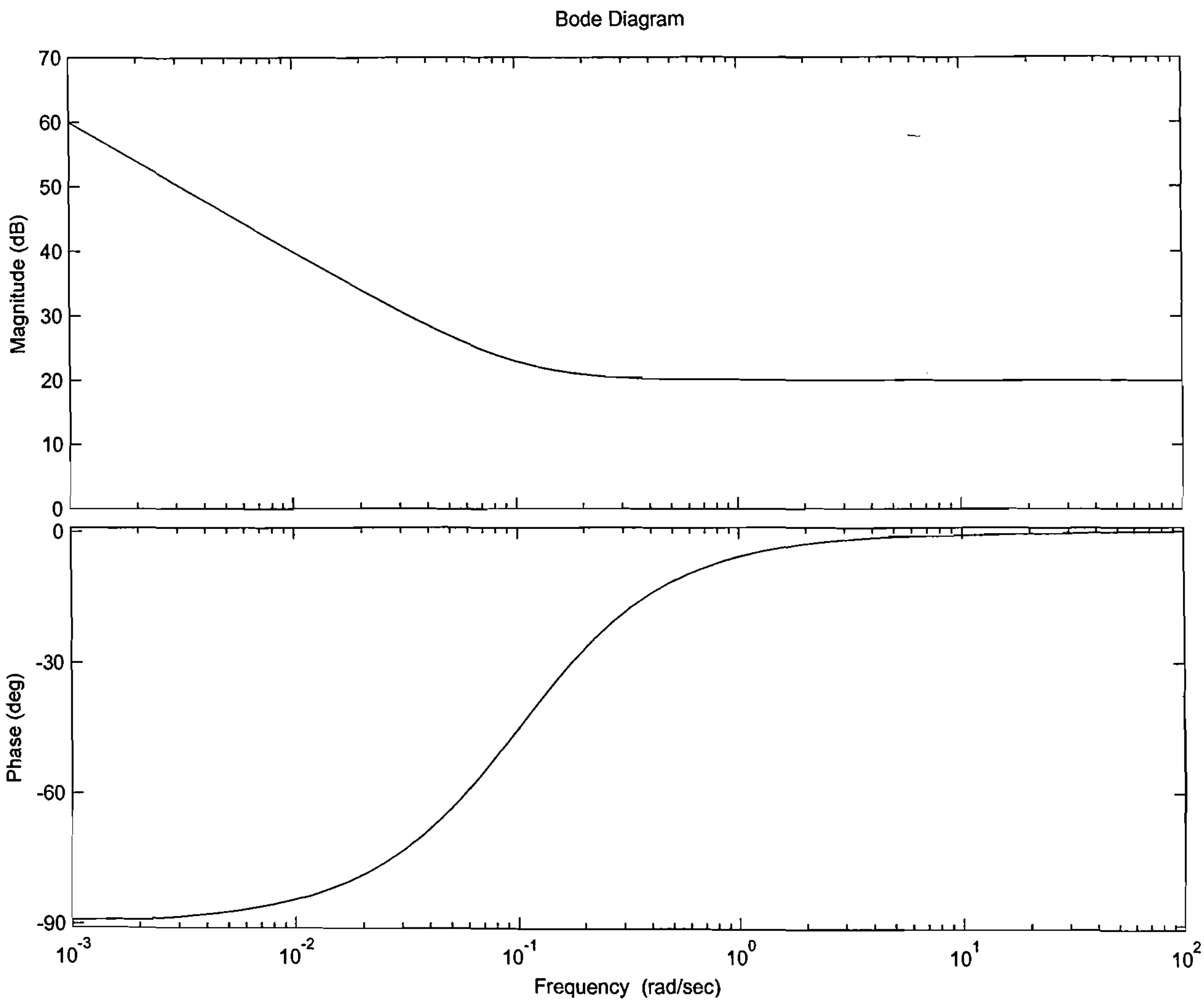
$\frac{1}{A_{R2}} < K < \frac{1}{A_{R3}}$ or

$K > \frac{1}{A_{R4}}$.

Aufgabe 6

i) PI, $K = 10$, $T_I = 10$

j)



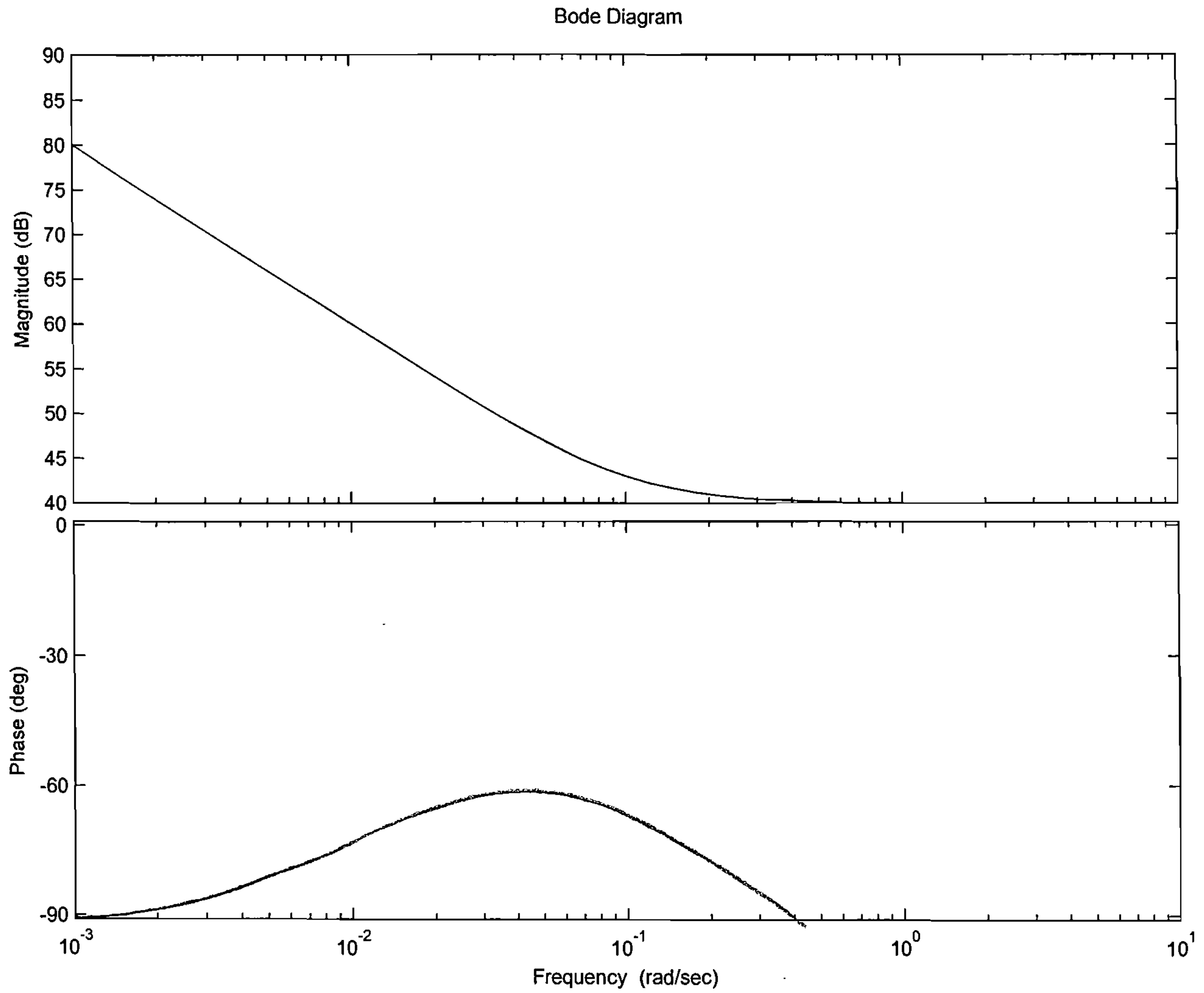
No A_R, no ϕ_R

k) The corner frequencies do not change if the magnitude doupled / halved.

Aufgabe 6

e) The phase is changing; the magnitude stays the same.

Example:



in Ergänzung zu Aufgabe 5

a) $\dot{y}(t) = \frac{1}{A} q(t)$ (1)

Laplace transfom of (1)

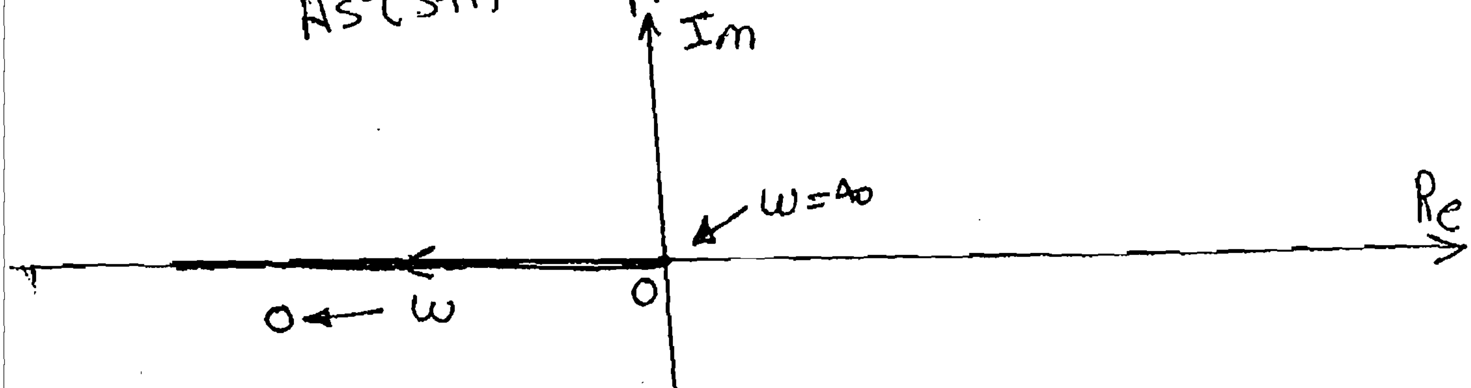
$$Y(s) = \frac{1}{A}\cdot\frac{1}{s} Q(s) \Rightarrow G(s) = \frac{Y(s)}{Q(s)} = \frac{1}{A\cdot s}$$

b) 1. PIT_1-element: $H_1(s) = K\frac{(1+\frac{1}{T_I s})}{(1+T_I s)} = K\frac{(1+\frac{1}{s})}{(1+s)}$

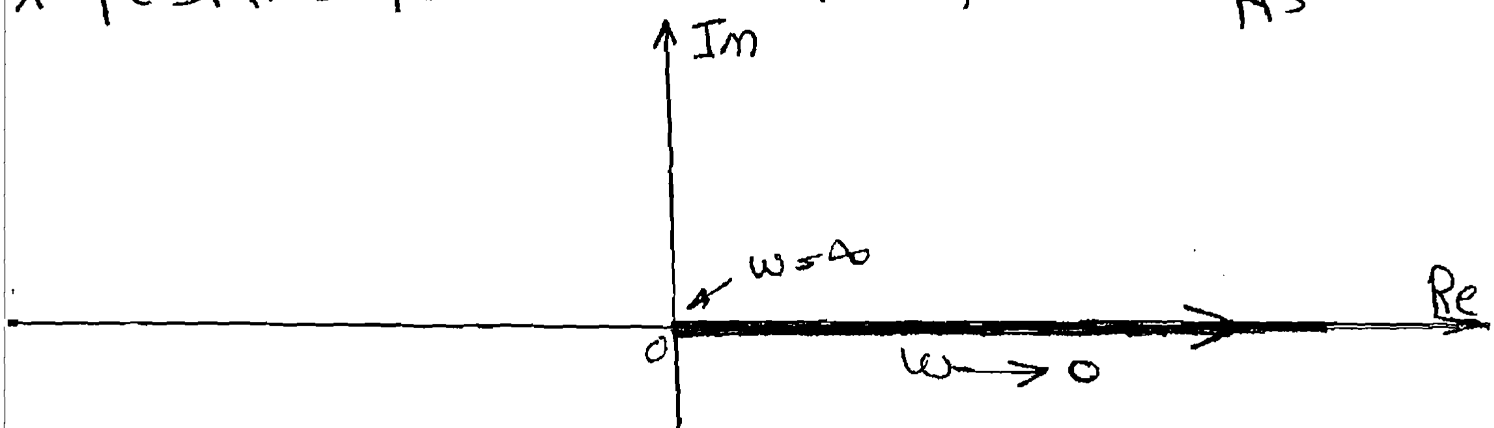
* Negative feedback:

$$C_{o1}(s) = H_1(s)\cdot G(s) = \frac{K(1+\frac{1}{s})}{(1+s)}\cdot\frac{1}{As} = \frac{K(\frac{s+1}{s})}{As(1+s)}$$

$$C_{o1}(s) = \frac{K(s+1)}{As^2(s+1)} = \frac{K}{As^2}$$ $K > 0$



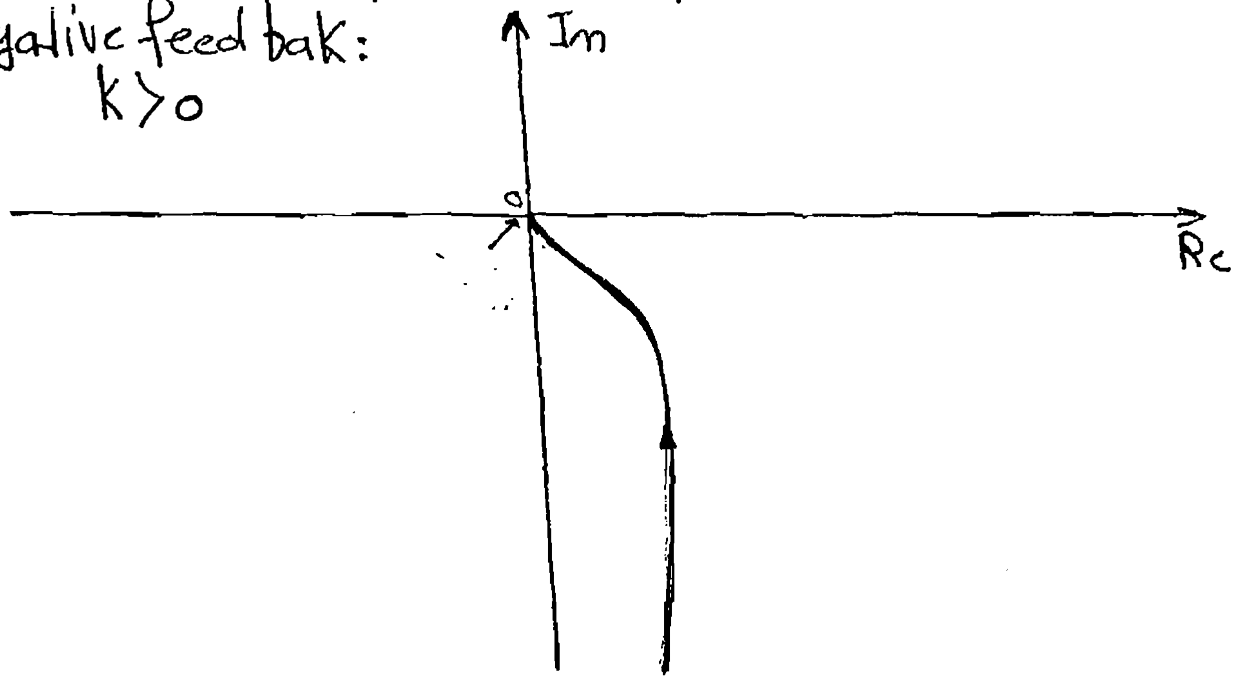
* Positive feedback: $K < 0$ & $C_{o2} = \frac{K}{As^2}$



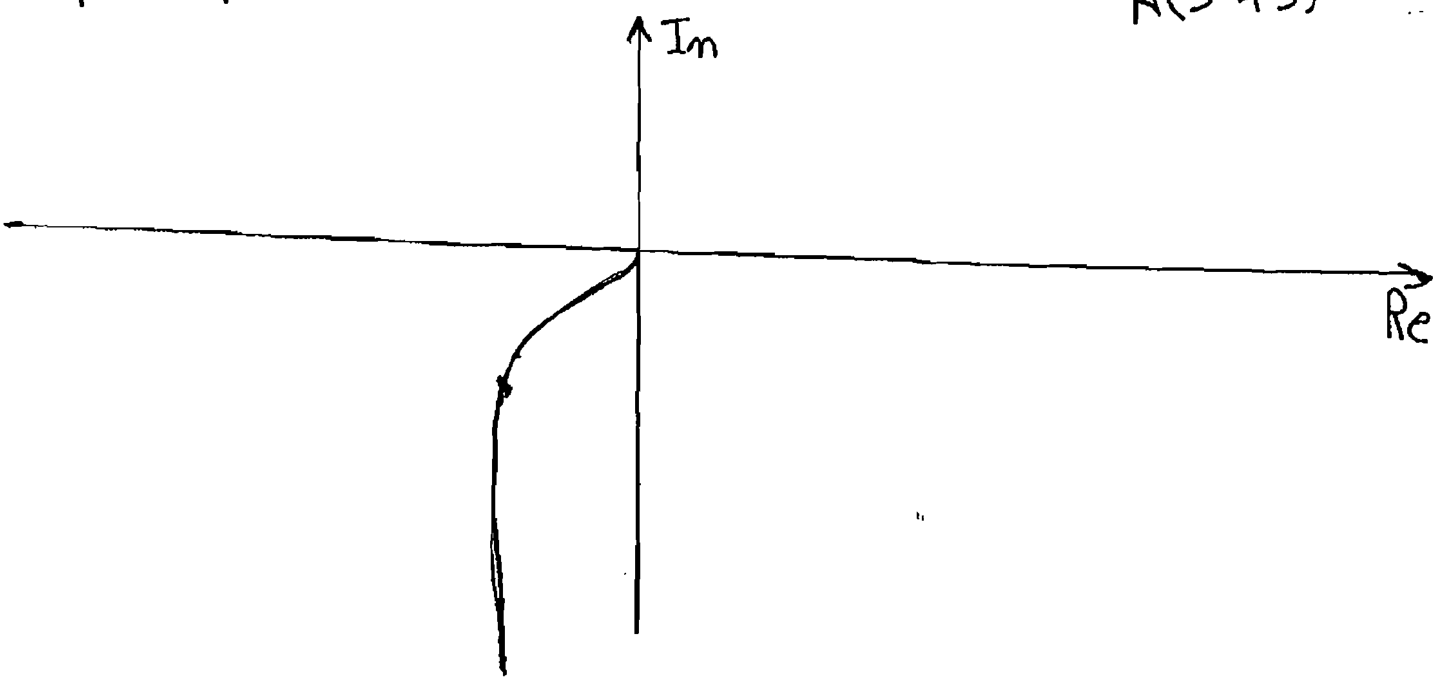
2. PD T1-element: $H_2(s) = \frac{K(1+2s)}{(1+T_1 s)} = K \frac{(1+2s)}{(1+s)}$ (2)

$$C_{o3} = H_2(s) \cdot G(s) = \frac{K(1+2s)}{As(1+s)} = \frac{K(1+2s)}{A(s^2+s)}$$

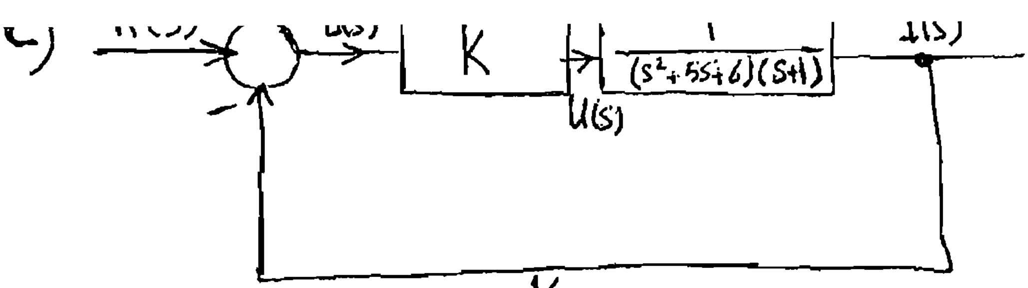
* Negative feed bak:
  $K > 0$



* Positive feedback: $K > 0$ & $C_{o3} = \frac{K(1+2s)}{A(s^2+s)}$



The system can be asymptotic only with PDT1-element and negative feedback for $\boxed{K > 0}$



3

$$C(s) = \frac{\dfrac{K}{(s^2+5s+6)(s+1)}}{1+\dfrac{K}{(s^2+5s+6)(s+1)}}$$

$$C(s) = \frac{\cancel{\dfrac{K}{(s^2+5s+6)(s+1)}}}{\dfrac{(s^2+5s+6)(s+1)+K}{\cancel{(s^2+5s+6)(s+1)}}}$$

$$C(s) = \frac{K}{s^3+s^2+5s^2+6s+6+K+5s}$$

$$C(s) = \frac{K}{s^3+6s^2+11s+6+k}$$

Characteristic equation:

$$\left.\begin{aligned} s^3+6s^2+11s+6+K &= 0 \\ a_0s^3+a_1s^2+a_2s+a_3 &= 0 \end{aligned}\right\} \Rightarrow$$

$a_0 = 1$ & $a_1 = 6$ & $a_2 = 11$ & $a_3 = 6+K \Rightarrow \boxed{K > -6}$

$\Delta_1 = |a_1| = 1 > 0$

$$\Delta_2 = \begin{vmatrix} a_1 & a_3 \\ a_0 & a_2 \end{vmatrix} > 0 \Rightarrow \begin{vmatrix} 6 & 6+K \\ 1 & 11 \end{vmatrix} > 0$$

$66 - 6 - K > 0 \Rightarrow 60 - K > 0 \Rightarrow \boxed{K < 60}$

The system is stable for $\boxed{-6 < K < 60}$

d) Open-loop system:

$$C(s) = \frac{K}{(s+1)(s+2)(s+3)} \quad ; K = 6$$ 4

$$C(s) = \frac{6}{(s+1)(s+2)(s+3)}$$

No zeros & Poles: $P_1 = -1$, $P_2 = -2$, $P_3 = -3$.

$$C(s) = \frac{\cancel{6}}{\cancel{6}\left(1+\frac{s}{1}\right)\left(1+\frac{s}{2}\right)\left(1+\frac{s}{3}\right)}$$

$$C(s) = \frac{1}{\left(1+\frac{s}{1}\right)\left(1+\frac{s}{2}\right)\left(1+\frac{s}{3}\right)}$$

$\omega_{o1} = 1$ rad/sec & $\omega_{o2} = 2$ rad/sec & $\omega_{o3} = 3$ rad/sec