Reading-up-time

For reviewing purposes of the problem statements, there is a "reading-up-time" of **10 minutes** prior to the official examination time. During this period it is **not** allowed to start solving the problems. This means explicitly that during the entire "reading-up-time" no writing utensils, e.g. pen, pencil, etc. at all are allowed to be kept on the table. Furthermore the use of carried documents, e.g. books, (electronic) translater, (electronic) dictionaries, etc. is strictly forbidden. When the supervisor refers to the end of the "reading-up-time" and thus the beginning of the official examination time, you are allowed to take your utensils and documents. Please **then**, begin with filling in the **complete** information on the titlepage and on page 3.

Good Luck!

LAST NAME	
FIRST NAME	
MATRIKEL-NO.	
TABLE-NO.	

Klausurunterlagen

Ich versichere hiermit, dass ich sämtliche für die Durchführung der Klausur vorgesehenen Unterlagen erhalten, und dass ich meine Arbeit ohne fremde Hilfe und ohne Verwendung unerlaubter Hilfsmittel und sonstiger unlauterer Mittel angefertigt habe. Ich weiß, dass ein Bekanntwerden solcher Umstände auch nachträglich zum Ausschluss von der Prüfung führt. Ich versichere weiter, dass ich sämtliche mir überlassenen Arbeitsunterlagen sowie meine Lösung vollständig zurück gegeben habe. Die Abgabe meiner Arbeit wurde in der Teilnehmerliste von Aufsichtsführenden schriftlich vermerkt.

The above required statements as well as the signature are mandatory at the beginning of the exam.

Duisburg, ______________ ____
(Date) (Student's signature)

Falls Klausurunterlagen vorzeitig abgegeben: ______________Uhr

Bewertungstabelle

Aufgabe 1	
Aufgabe 2	
Aufgabe 3	
Gesamtpunktzahl	
Angepasste Punktzahl	
%	
Bewertung gem. PO in Ziffern	

____

(Datum und Unterschrift 1. Prüfer, Univ.-Prof. Dr.-Ing. Dirk Söffker)

____

(Datum und Unterschrift 2. Prüfer, Prof. Dr.-Ing. Yan Liu)

____

(Datum und Unterschrift des für die Prüfung verantwortlichen Prüfers, Söffker)

Fachnote gemäß Prüfungsordnung:

☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
1,0	1,3	1,7	2,0	2,3	2,7	3,0	3,3	3,7	4,0	5,0
sehr gut		gut			befriedigend			ausreichend		mangelhaft

Bemerkung: ____

Attention: Give your answers to ALL problems directly below the questions in the exam question sheet.

You are NOT allowed to use a pencil and also NOT red color (red color is used for corrections).

This exam is taken by me as a
☐ mandatory (Pflichtfach)
☐ elective (Wahlfach)
☐ prerequsite (Auflage)
subject (cross ONE option according to your own situation).

Maximum achievable points:	**80**
Minimum points for the grade 1,0:	**95%**
Minimum points for the grade 4,0:	**50%**

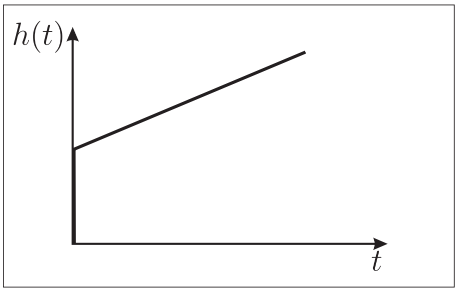
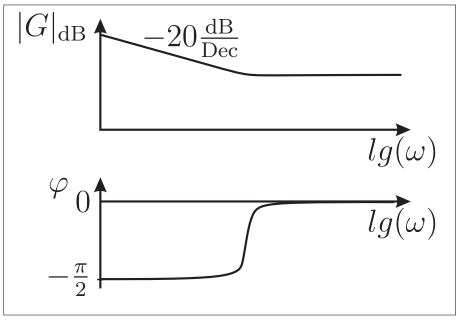
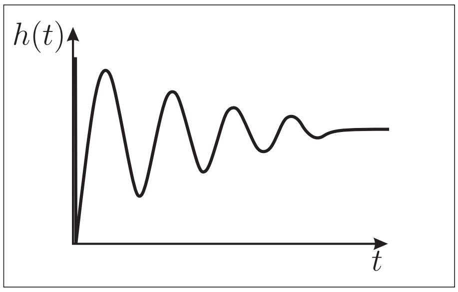
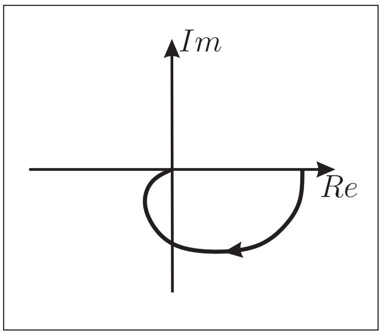
General hints:

1) For the multiple-choice and multiple-choice-similar tasks the following rules are effective:
   i) For correct answers of exam task parts the desired number of points will be given.
   ii) For noncorrect answers of exam task parts the desired number of points will be counted negative.
   iii) No answering will neither lead to positive nor to negative points.
   iv) The points of the task will be summarized. The whole number can not be smaller than zero.
2) If in the exam tasks no information is given for the valid range of numbers for time constants or masses etc. : take for time constants (in sec.), for masses (in kg) positive numbers.
3) If in the exam tasks no information is given for applying negative or positive feedback: use the usual negative feedback.

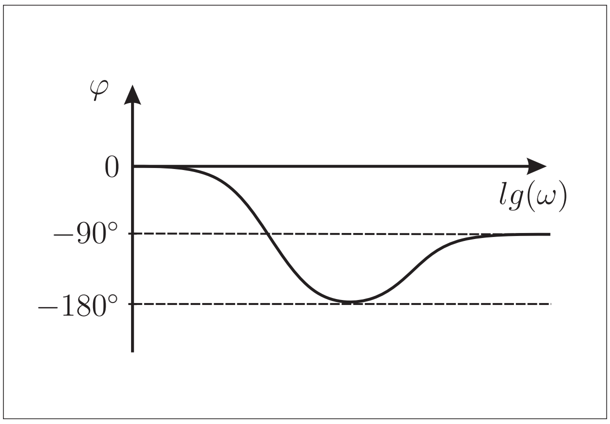
Problem 1 (36 Points)

1a) (3 × 5 × 1 Point, 15 Points)
Which of the following statements are true and which are false? (All underlying relationships have been discussed as part of the lecture control engineering.)

No.	Task/Question/Judgement	True	False
A.1)	Time-variant processes can only be described accurately in frequency domain.	○	○
A.2)	Using the initial and final value theorem of the Laplace transformation, the limits of the phase shift in time domain for $s \to 0$ and $s \to \infty$ can be determined.	○	○
A.3)	State space models are descriptions only in time domain.	○	○
A.4)	The general algorithm of the Laplace transformation for a function $f(t)$ is $\mathcal{L}\{f(t)\} = \int\limits_0^\infty f(t)e^{-st}\,dt$ with $s \in \mathbb{C}$.	○	○
A.5)	The signal $u(t) = 2\cdot 1(t-3)+\delta(t)+e^{-5t}\cdot 1(t)$ can be described in frequency domain as $u(s) = \frac{2}{s}\cdot e^{-3s} + 1 + \frac{1}{s+5}$.	○	○

No.	Task/Question/Judgement	True	False
B.1)	The following figures describe a principally identical transfer behavior:  	○	○
B.2)	The following figures describe a principally identical transfer behavior:  	○	○
B.3)	The system with the transfer function $G(s) = \dfrac{3s+1}{(s^2+2s+1)(s+1)}$ can be described in time domain by $\dddot{y} + 3\ddot{y} + 3\dot{y} + y = 3\dot{u} + u$.	○	○
B.4)	The relationship between time and frequency domain is defined by $h(t) = \mathcal{L}\{H(s)\}$.	○	○
B.5)	Time delays in the transfer behavior of systems are described in frequency domain by zeros and equivalently in time domain by higher order derivatives of the input variables.	○	○

☐

No.	Task/Question/Judgement	True	False
C.1)	A system with the transfer function $G(s) = \frac{K(s+2)}{s^2+2s+1}$ can have the following phase shift behavior: 	◯	◯
C.2)	Based on the position of the poles, the state stability of a linear, time-invariant SISO system can be determined.	◯	◯
C.3)	Poles of a system are always also eigenvalues of the system.	◯	◯
C.4)	The stimulation with certain frequencies of a system with conjugate complex poles leads always to a resonance.	◯	◯
C.5)	It applies to a stable system behavior: the phase shift for $\omega \to \infty$ has to be larger than $0°$.	◯	◯

☐

1b) (16 Points)
A technical system is described by the block diagram shown in Figure 1.1.

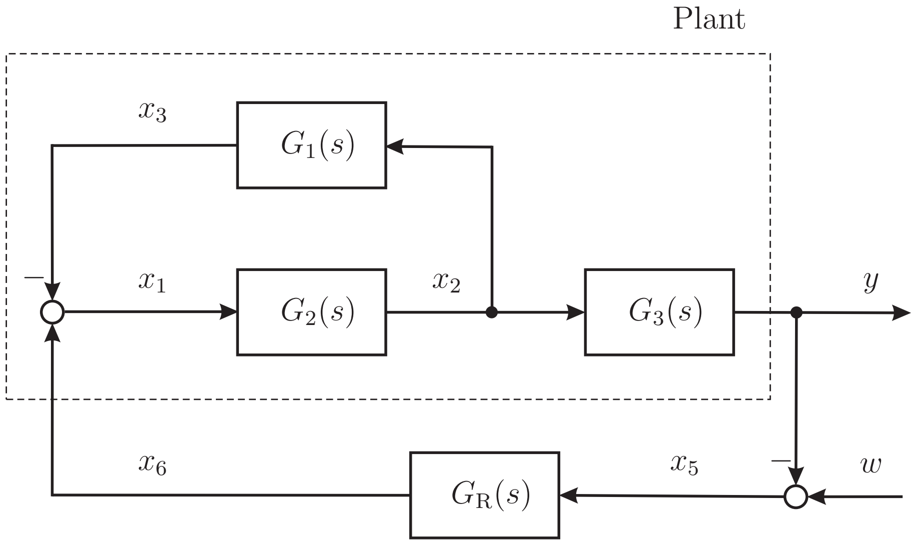


Figure 1.1: Block diagram of a technical system

The transfer functions of the elements are

$$G_1(s) = \frac{1}{2},$$
$$G_2(s) = 1 + s,$$
$$G_3(s) = \frac{1}{s^2 + s + 1}\text{ , and}$$
$$G_R(s) = \frac{1}{s}.$$

i) (6 Points)

Determine the transfer function of the plant $G_{\mathrm{S}}(s) = \dfrac{y(s)}{x_6(s)}$ and classify the transfer behavior.

For the following tasks ii) and iii), the transfer function with respect to the desired value is assumed as

$$G_{\mathrm{W}}(s) = \frac{K_{\mathrm{P}}(\tilde{T} + s)}{5s^3 + 10s^2 + 3s + 1 + K_{\mathrm{P}}}$$

with K_{P}, $\tilde{T} > 0$.

ii) (5 Points)
Using the Hurwitz criterion, determine the allowed range of the controller gain K_{P}, for which the closed loop is asymptotically stable.

iii) (5 Points)
Discuss, if the given controller with the parameters $K_{\mathrm{P}} = 1$ and $\tilde{T} = 2$ is suitable for stationary acurate control. At first, calculate the stationary final value for the desired value $w(t) = 1(t)$.

1c) (1 × 5 × 1 Point, 5 Points)
A system with the transfer function

$$G(s) = \frac{K(s+1)}{s^2+s+1} \text{ with } K > 0$$

should be controlled with negative feedback by a P-controller with the gain K_R. Evaluate the statements in the table below.

No.	Task/Question/Judgement	True	False
1)	The controlled system shows a stationary final value $y(t \to \infty) = \frac{1}{1+KK_\mathrm{R}}$ for the transfer behavior with respect to the desired value with the input signal $w(t) = 1(t)$.	○	○
2)	For $KK_\mathrm{R} \to \infty$, the remaining control difference is $e(t \to \infty) = \infty$, with the input signal $w(t) = 1(t)$.	○	○
3)	For the control gain $K_\mathrm{R} > -\frac{1}{K}$, the closed loop is asymptotically stable.	○	○
4)	The parameter K_R of the controller affects the oscillation behavior of the closed loop.	○	○
5)	Assume the parameters are given as $K = 5$ and $K_\mathrm{R} = 5$. The controlled system has a conjugate complex pole.	○	○

Σ

Problem 2 (29 Points)

2a) (1 × 3 × 1 Point, 3 Points)
Evaluate the statements in the table below.

No.	Task/Question/Judgement	True	False
1)	In a series connection with other transfer elements, an element with time delay results in a polar plot, which surrounds the origin of the complex area a lot of times.	○	○
2)	A system with proportional behavior should be controlled with the goal to have an as fast as possible response. This goal can be achieved easily by integrating a differential part in the feedback.	○	○
3)	Minimum-phase systems are systems, that have no time delay and only poles and zeros with non-negative real part.	○	○

☐

2b) (16 Points)
The transfer function of a plant is described by

$$G_{\mathrm{S}}(s) = \frac{K_{\mathrm{Strecke}}(T_{\mathrm{D}_1}s + 1)}{\frac{1}{\omega_0^2}s^2 + \frac{2D}{\omega_0}s + 1}$$

with $K_{\mathrm{Strecke}} = 20$, $T_{\mathrm{D}_1} = \frac{1}{6}$, $\omega_0 = 3$, and $D = \frac{1}{3}$. For better dynamic behavior a controller with the transfer function

$$G_{\mathrm{R}}(s) = \frac{K_{\mathrm{R}}(T_{\mathrm{D}_2}s + 1) \cdot e^{-T_{\mathrm{t}}s}}{T_1 s + 1}$$

with $T_{\mathrm{D}_2} = 1$, $T_1 = \frac{1}{5}$, and $T_{\mathrm{t}} = 0.1$ is designed with negative feedback.

i) (2 Points)
Which poles and zeros has the transfer function of the open loop?

ii) (4 Points)
Discuss the stability of the closed loop according to K using the root locus method.

iii) (6 Points)
Draw the Bode-diagram qualitatively (real and approximated behavior) of the open loop for $K_{\mathrm{R}} = 0.5$ (Hint: $\log_{10}(10) = 1$).

iv) (4 Points)
The given controller is replaced by the human, whose behavior can be described by a PT_2-element. This element has a double real pole with negative real part. Discuss the stability of the closed loop with the human as controller according to K.

2c) (2 × 5 × 1 Point, 10 Points)
The measurement of the transfer behavior of a technical system is shown as Bode-diagram in Figure 2.1. The system is controlled by a P-controller ($K_\mathrm{R} = 1$) with negative feedback.

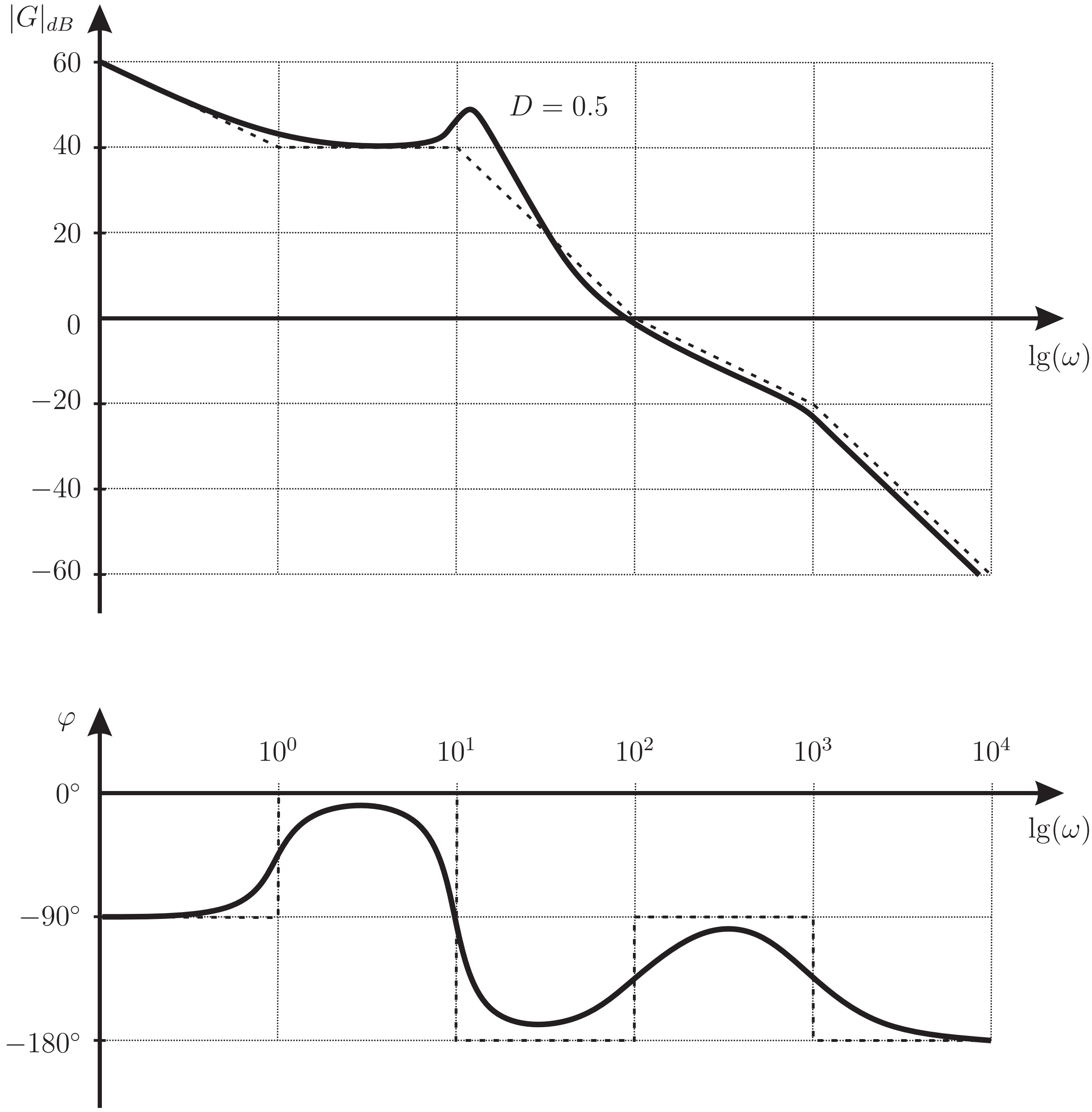
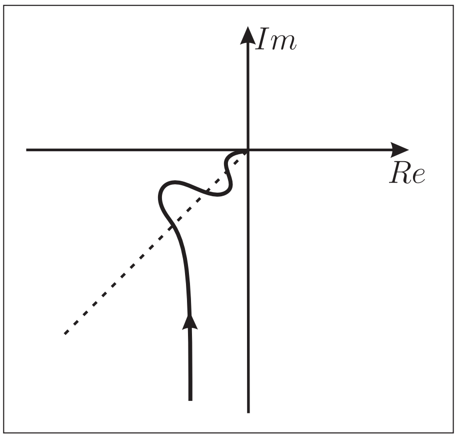


Figure 2.1: Bode-diagram of a technical system

Evaluate the statements in the tables below.

No.	Task/Question/Judgement	True	False
A.1)	It is an integral system.	◯	◯
A.2)	It is a non-linear system.	◯	◯
A.3)	The phase margin of the system at the gain crossover frequency ω_S is larger than 45°.	◯	◯
A.4)	The closed loop is stable.	◯	◯
A.5)	The polar plot of the system ends in the origin of the s-plane for $\omega \to \infty$.	◯	◯

☐

No.	Task/Question/Judgement	True	False
B.1)	The step response of the system has a time delay of $T_t = 0.1$ sec.	◯	◯
B.2)	It is a minimum-phase system.	◯	◯
B.3)	The poles of the system are $s_{1/2} = -5 \pm \sqrt{75}j$ and $s_3 = -1000$.	◯	◯
B.4)	The zeros of the system are $s_{01} = -1$ and $s_{02} = -100$.	◯	◯
B.5)	The open loop can show the following polar plot. 	◯	◯

☐

Σ ☐

Problem 3 (15 Points)

3a) (7 Points)
A system with the transfer function

$$G_{\mathrm{S}}(s) = \frac{s+3}{s^2-3s+2}$$

is controlled with negative feedback by a controller with the transfer function

$$G_{\mathrm{R}}(s) = \frac{s}{s^2+4s+5}.$$

i) (2 Points)
The open loop has the following pole/zero-plot.

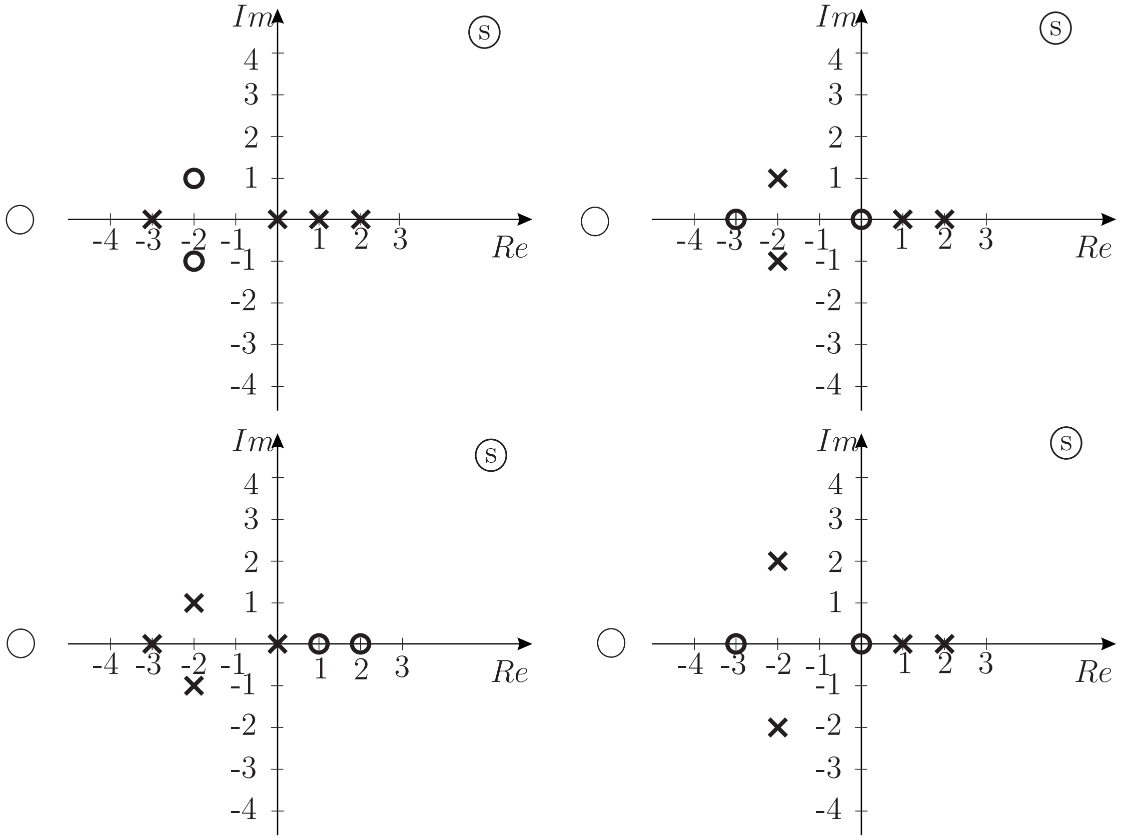


Figure 3.1: Pole/zero-plot

ii) (1 × 5 × 1 Point, 5 Points)
Evaluate the statements in the table below based on the given control loop. (Assume the center of the asymptotes as $\sigma_{\mathrm{W}} = -2$.)

No.	Task/Question/Judgement	True	False
1)	The uncontrolled system is able to oscillate.	◯	◯
2)	The open loop is boundary stable.	◯	◯
3)	For the gain $K \to \infty$ the closed loop is boundary stable.	◯	◯
4)	An asymptotically stable behavior can be obtained by a suitable control parameter tuning.	◯	◯
5)	A behavior without oscillations can be obtained by a suitable control parameter tuning.	◯	◯

☐

3b) (1 × 5 × 1 Point, 5 Points)
A system with the pole/zero-plot shown in Figure 3.2 is controlled with negative feedback by a controller with P-behavior and the control gain K_R.

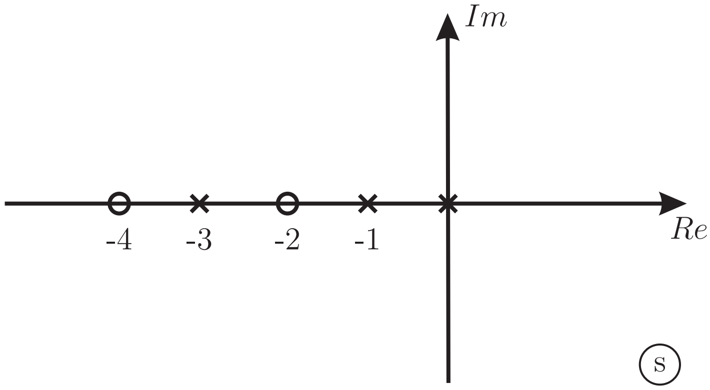


Figure 3.2: Pole/zero-plot

Evaluate the statements in the table below.

No.	Task/Question/Judgement	True	False
1)	The closed loop is asymptotically stable for all gains $K > 0$.	○	○
2)	The damping is $D < 1$ for all control gains.	○	○
3)	By adding a zero at $s_n = -5$, the stability behavior of the closed loop changes fundamentally.	○	○
4)	Instead of the zero in 3b)3), a conjugate complex pole at $s_{4/5} = -5 \pm \sqrt{3}j$ is added. This changes fundamentally the overall system behavior of the closed loop.	○	○
5)	The P-controller is replaced by a PDT_1-controller, which has a zero $s_n = -6$ and an unstable pole s_i. The closed loop is unstable for all control gains.	○	○

3c) (3 Points)
The measurement of the transfer behavior of an open loop results in the Bode-diagramm shown in Figure 3.3.

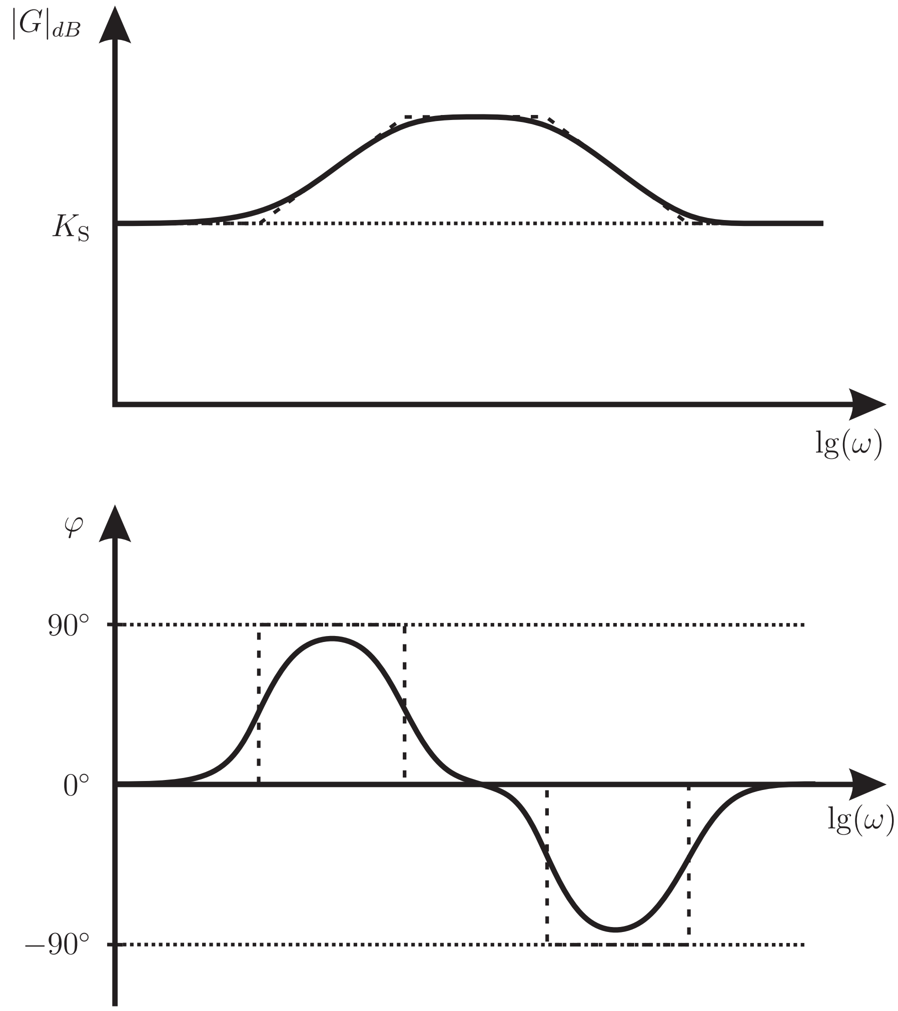


Figure 3.3: Bode-diagram

Draw the polar plot of the open loop qualitatively.

$\sum$