UNIVERSITÄT DUISBURG-ESSEN
Fakultät für Ingenieurwissenschaften, Abt. Maschinenbau und Verfahrenstechnik
Lehrstuhl Steuerung, Regelung und Systemdynamik
Control Engineering July 19th, 2013

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)

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

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(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.

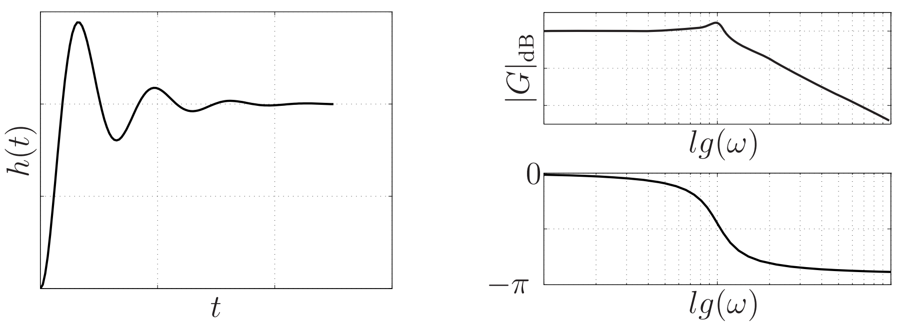
Problem 1 (32 Points)

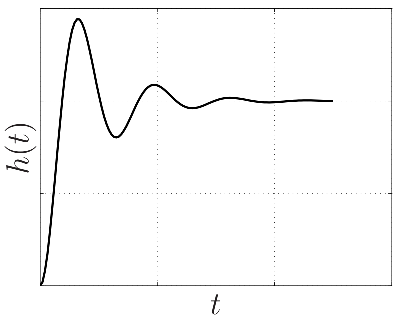
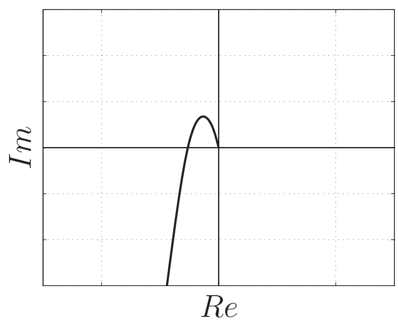
1a) (3 × 5 Points, 15 Points)
Determine the differences between time and frequency domain based on the following descriptions/statements. Which of the following statements are true and which are false? (All underlying relationships have been taught as part of the lecture control engineering.)

No.	Task/Question/Judgement	True	False
a.1)	By using Laplace transformation, time variable signals can be described in the same quality in frequency domain.	○	○
a.2)	The signal $u(t) = 1(t) + \delta(t-5)$ can be represented by $u(s) = \frac{1}{s} + e^{-5s}$ in frequency domain.	○	○
a.3)	Step responses are description methods in frequency domain.	○	○
a.4)	The signal $y(s) = G(s)\,u(s)$ with $G(s) = \frac{2}{s}$ and $u(s) = \frac{1}{s}$ describes the step response of an I-system with $y(s) = \frac{2}{s^2}$.	○	○
a.5)	The Bode-diagram describes the trajectory of the Bode in a diagram form. It can be distinguished between the large and small Bode-diagram.	○	○

☐

b.1)	The following figures are describing a principally identical system behavior: (see figure below)	○	○



No.	Task/Question/Judgement	True	False
b.2)	The following figures are describing a principally identical system behavior:  	○	○
b.3)	The polar plot describes the frequency-dependent amplitude and phase behavior in a similar way as the Bode-diagram.	○	○
b.4)	Using the initial and final value theorem of the Laplace transform, the limits of the corresponding time behavior can be determined from the Laplace transformed functions.	○	○
b.5)	The Laplace transform of $y(s)$ for the cases with $y_1(t=0)=0$ and $y_2(t=0)=1$ are identical for $u(t)=\left[\frac{1}{4}\,t\,sin(2t)+sin(4t)-4\,t\,cos(8t)\right]\cdot 1(t)$ and $G(s)=\frac{1}{s+1}$.	○	○

c.1)	Based on the position of the poles, the I/O-stability of a linear, time-invariant SISO-system can be determined.	○	○
c.2)	A stable proportional system is excited by an input signal $u(t)=2e^{3t}$. The output $y(t)$ of the system is bounded.	○	○
c.3)	The I/O-behavior of a PI-controller can be described in frequency domain by the equation $y=K(u+\tilde{T}_{\mathrm{I}}\int u\,dt)$.	○	○
c.4)	The relation between time domain and frequency domain is given by $G(s)=\mathcal{L}\{g(s)\}$.	○	○
c.5)	The stability analysis of linear systems is different in time and frequency domain due to the non-steady-state character of unstable systems that can only be addressed in time domain.	○	○

1b) (7 Points)
The shown approximated behavior of a measured polar plot has to be analyzed.

i) Classify the system behavior, so far that is possible.
ii) Sketch qualitatively the corresponding Bode-diagram from $\omega = 0$ to $\omega = \infty$.
iii) Is the illustrated system a minimum phase system (Yes/no and why)?
iv) Is the illustrated system a stable system (Yes/no and why)?

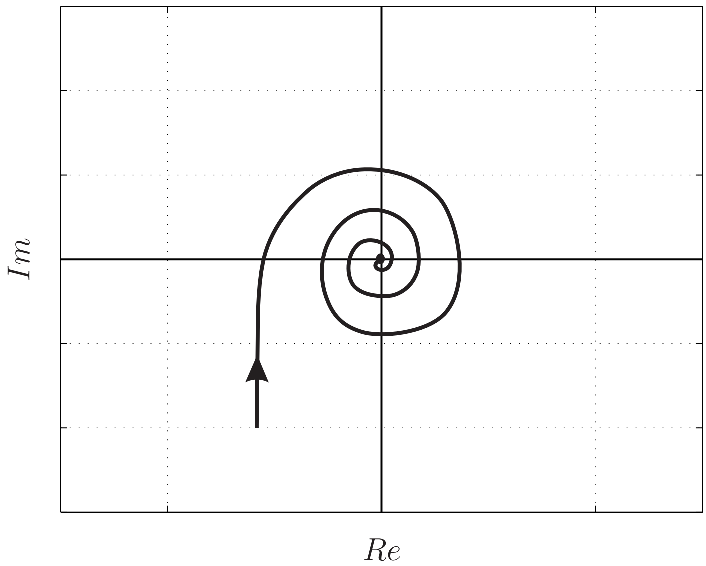


Figure 1.1: Polar plot of system

1c) (10 Points)
The transfer function of a plant is

$$G_\mathrm{S}(s) = \frac{1}{(1+T_1 s)(1+T_2 s)}\,.$$

A PI-controller using negative feedback with

$$G_\mathrm{R}(s) = K(1 + \frac{1}{T_\mathrm{I} s})$$

is applied to improve the dynamical behavior of the system.

i) State the transfer function, poles, and zeros of the open loop.

ii) State the amplitude transfer function $|G_\mathrm{o}(j\omega)|$.

iii) State the phase shift $\varphi_\mathrm{o}(\omega)$.

iv) Which condition should the parameter T_I fulfill to have an asymtotically stable closed-loop system?

v) For $K = 1$, $T_1 = T_2 = T$, and $T_\mathrm{I} = \frac{T}{\sqrt{3}}$ the crossover frequency is $\omega_s = \frac{1}{T}$. Determine the phase margin ϕ_R. (Hint: Use ϕ_R=arctan(value).)

□

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Problem 2 (33 Points)

2a) (3 Points)
Evaluate the statements in the table below.

No.	Task/Question/Judgement	True	False
1)	Time delay elements affect the phase by an additional phase delay of $\Delta\varphi_{\text{tot}} = -\omega T_{\text{t}}$, with T_{t} defined as delay time.	○	○
2)	A system is described by $$G(s) = \frac{1}{(s-3)(s+4)(s-5)s}.$$ The I/O-behavior of the system is a minimum phase system.	○	○
3)	A system with integral behavior has to be considered for step-like reference values. To achieve no steady state error, for example, a PT_1-controller can be easily integrated in the feedback. The destabilization of the closed-loop system is impossible.	○	○

□

2b) (5 Points)
The typical frequency response of a loudspeaker box is illustrated in Figure 2.1 (solid lines: real measurement in black, approximated behavior in grey).

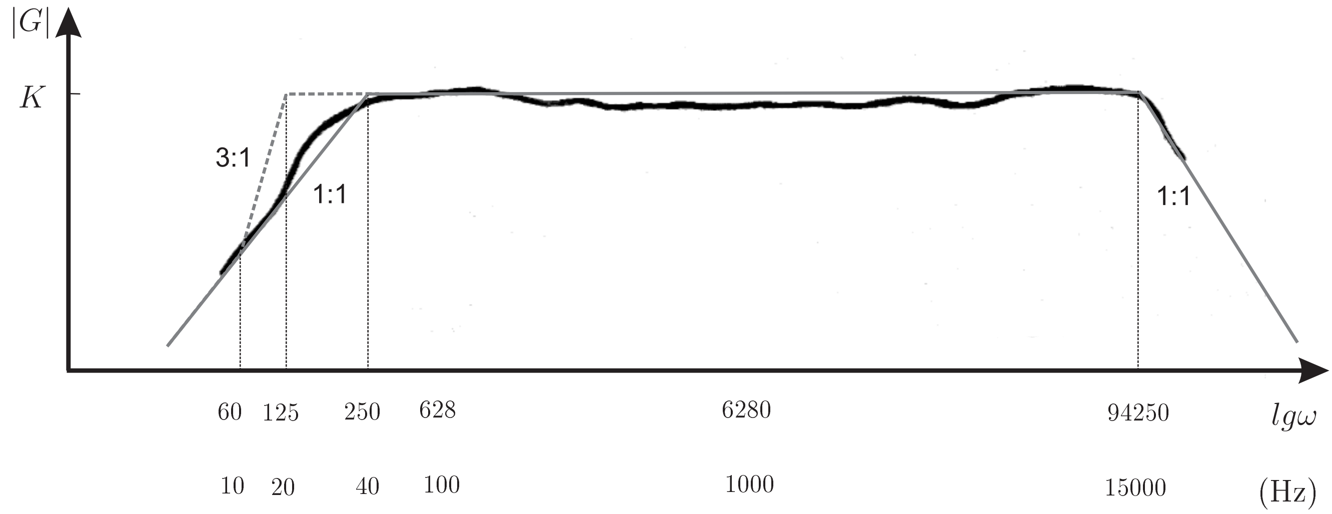

Figure 2.1: Typical frequency response of a loudspeaker box

i) Is the system stable? State reason.

ii) Determine the transfer behavior of the loudspeaker box in frequency domain (with pole/zero positions).

iii) A friend of lower frequency sound wants to improve the behavior of the loudspeaker in the low frequency region. The goal is to change the frequency behavior in the way shown with the grey dashed line. Design a suitable prefilter with minimal phase shift to achieve the goal.

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2c) (19 Points)
The dynamics of a technical system is described approximatively by the following Bode-diagram in Fig. 2.2.

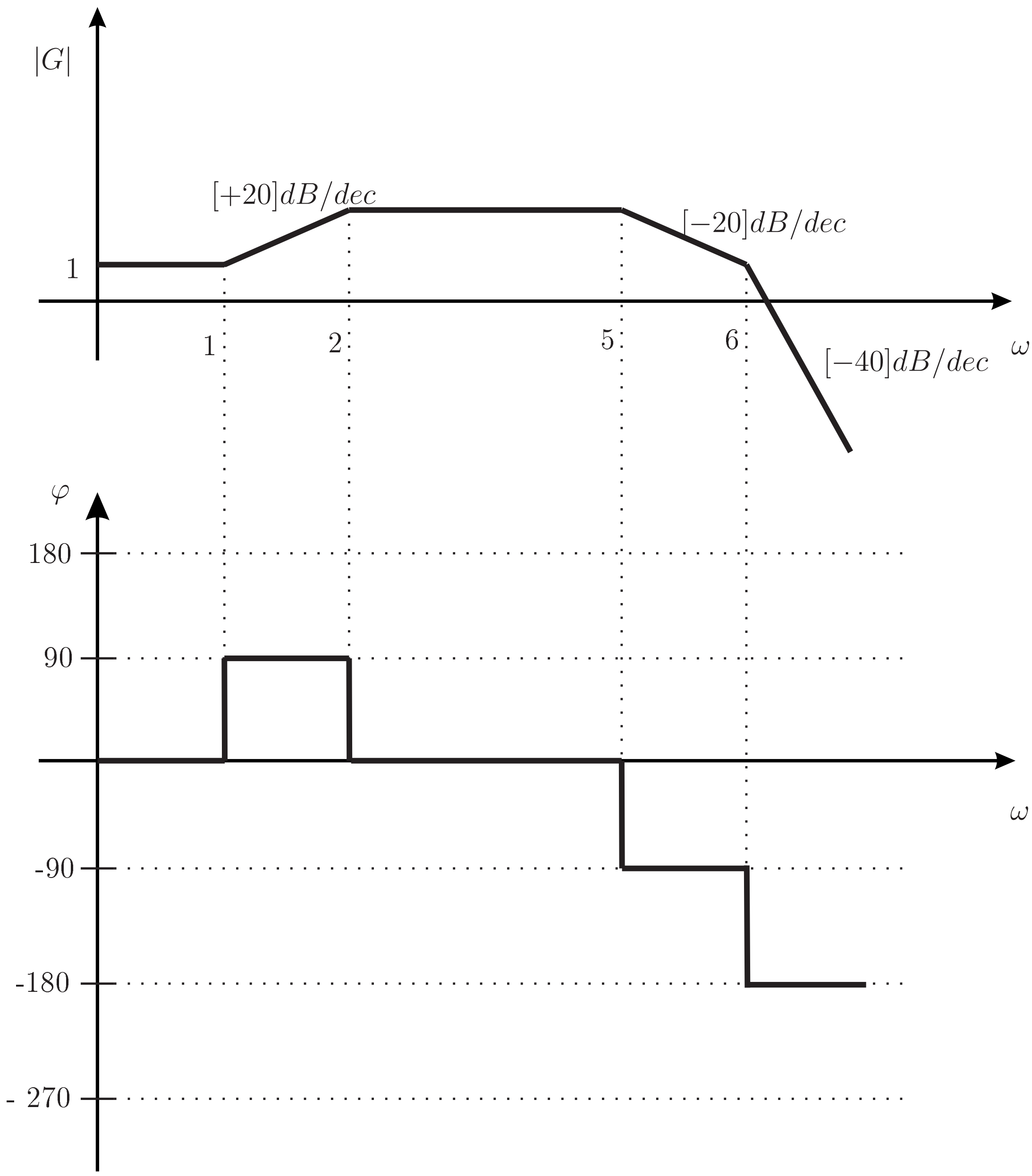

Figure 2.2: Bode-diagram of a technical system

The system is controlled using a filter $G_{\mathrm{R}}(s) = \dfrac{\frac{56}{3}(s-3)}{(s+4)(s+7)}$ in negative feedback.

i) State the poles and zeros of the open loop.

ii) Draw approximatively the Bode-diagram of the open loop. Indicate all poles and zeros.

iii) Indicate qualitatively the phase margin ϕ_R in the Bode-diagram.

iv) Is the behavior of the closed-loop system stable or unstable according to the amplitude and phase margin? State reason.

v) Assume that the zero in the filter is with negative real part. Which kind of behavior from the closed-loop system is expected with respect to stability? State reason with the help of a root locus sketch.

vi) A friend suggests a controller $G_{\mathrm{R2}}(s) = \frac{1}{T_1 s^2}$. Prove with root locus approach and state reasons about the usefulness of the suggested controller in comparison with the previous controller.

2d) (6 Points)

A system with the transfer function

$$G(s) = \frac{K}{s^2 + \tilde{D}s + 1}$$

has to be controlled using a I-controller with time constant T_I in negative feedback. Evaluate the statements in the table below.

No.	Task/Question/Judgement	True	False
1)	Regarding the reference behavior, the controlled system has a steady-state accuracy error of $e(t \to \infty) = \frac{K}{1+K}$.	○	○
2)	The controller leads to a stationary behavior without steady-state error and perfect compensation of disturbances.	○	○
3)	The parameter $\tilde{D}$ of the plant affects the oscillating behavior of the open loop system.	○	○
4)	The parameter T_I of the controller affects the oscillating behavior of the open loop system.	○	○
5)	An additional zero has a significant large influence on the damping behavior of the closed-loop system.	○	○
6)	Another additional zero leads to a further improvement of the damping behavior of the closed-loop system.	○	○

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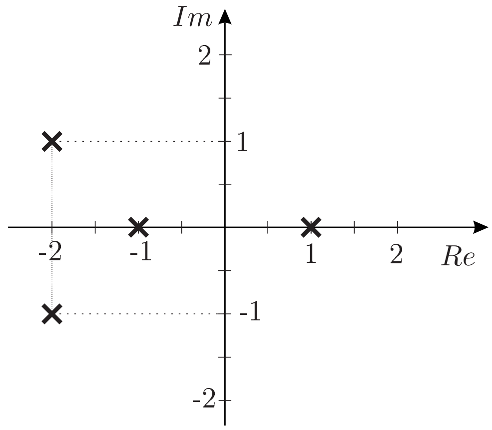
Problem 3 (15 Points)
The illustrated pole/zero-plot of the system to be controlled is given:



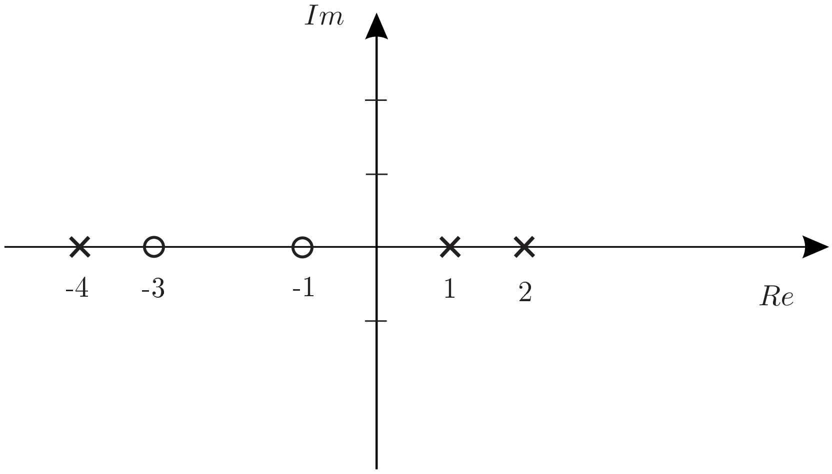
Firstly, the system is controlled using a PDT_1-controller.

3a) (5 Points)

No.	Task/Question/Judgement	True	False
1)	The uncontrolled system is unstable.	◯	◯
2)	For large gains, the controlled system is unstable.	◯	◯
3)	The PDT_1-controller is capable to stabilize the system for arbitrary gains.	◯	◯
4)	The filter $G_F(s) = \frac{(s+3)(s+4)}{(s+7)}$ as controller stabilizes the system for a certain parameter range.	◯	◯
5)	In principle, a controller of the type $G_\mathrm{R} = (s - T)$ with $T > 0$ could stabilize the system.	◯	◯

3b) (5 Points)

The system is controlled using a controller leading to the given pole/zero-plot of the open loop system:

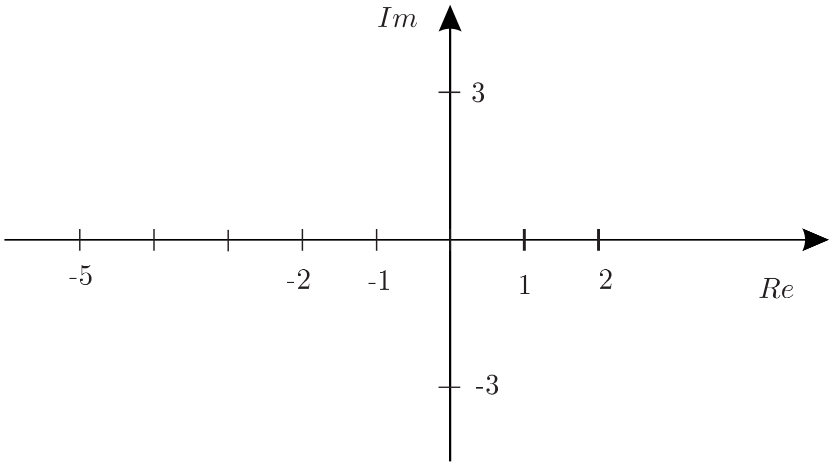


No.	Task/Question/Judgement	True	False
1)	For small gains $\tilde{K}$, the controlled system is asymptotically stable.	◯	◯
2)	The system does not show complex conjugate poles depending on the value of the gain $\tilde{K}$.	◯	◯
3)	The controlled system can be asymptotically stable.	◯	◯
4)	The controlled system is a minimum phase system.	◯	◯
5)	A zero $s_{\mathrm{n}} = -4$ is fundamentally changing the overall system behavior.	◯	◯

3c) (5 Points)

The system is controlled, so that the given open loop control $G_0(s)$ is given by

$$G_0 = \frac{(s+5+3j)(s+5-3j)}{(s+1)(s-2)(s+5)} \ .$$



No.	Task/Question/Judgement	True	False
1)	The open-loop system is unstable.	○	○
2)	For large gains $\tilde{K}$, the controlled system shows a damping coefficient $D < 1$.	○	○
3)	For large gains $\tilde{K}$, the controlled system becomes unstable.	○	○
4)	For small gains $\tilde{K}$ all poles are conjugate complex.	○	○
5)	Principally for the whole range of $\tilde{K}$: larger $\tilde{K}$ leads to larger damping coefficient.	○	○

□

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