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.

Duisburg, den __________ ________________________________
(Unterschrift der/des Studierenden)

Falls Klausurunterlagen vorzeitig abgegeben: ______________Uhr

Bewertungstabelle

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

____

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

____

(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:	**90**
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.

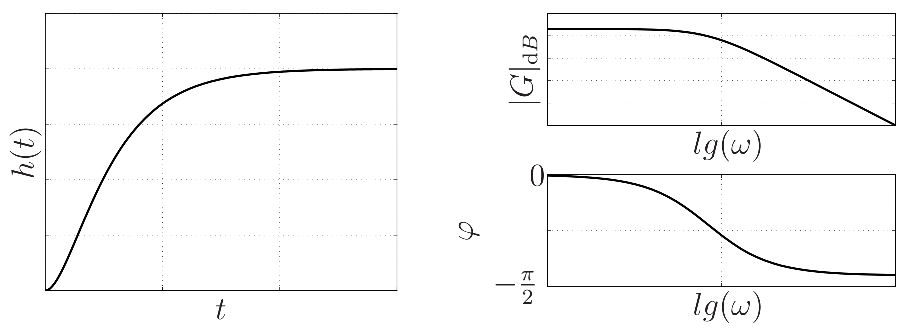
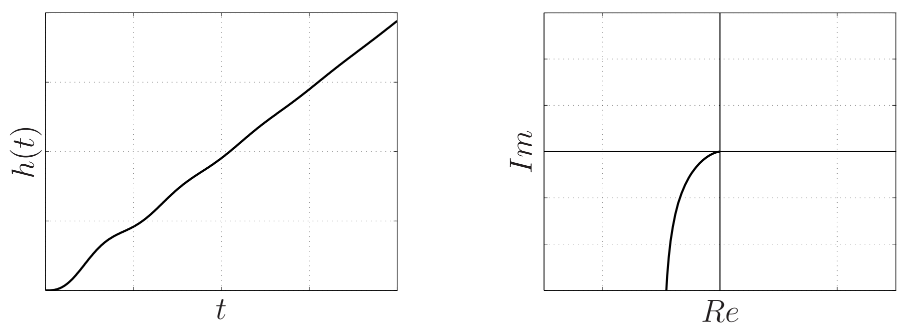
2) If in the exam tasks no information is given for the valid range of numbers for time constants or masses etc.: take for time constants (in sec.), for masses (in kg) positive numbers.

3) If in the exam tasks no information is given for applying negative or positive feedback: use the usual negative feedback.

UNIVERSITÄT DUISBURG-ESSEN
Fakultät für Ingenieurwissenschaften, Abt. Maschinenbau und Verfahrenstechnik
Lehrstuhl Steuerung, Regelung und Systemdynamik
Control Engineering July 20th, 2012

Problem 1 (30 Points)

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

No.	Task/Question/Judgement	True	False
1)	Time variant processes can only be described accurately in time domain.	○	○
2)	Time invariant processes can only be analyzed accurately in frequency domain.	○	○
3)	Transfer functions are describing techniques used in frequency domain.	○	○
4)	Using the initial and final value theorem of the Laplace transform, the the limits for the behavior of the amplitude in time domain for $t \to 0$ and $t \to \infty$ can be determined.	○	○
5)	The I/O-behavior of a PI-transfer element is defined in frequency domain by the equation $y = K(u + \frac{1}{T_\mathrm{I}} \int u \; dt)$.	○	○
6)	The following figures describe a principally identical transfer behavior: 	○	○
7)	The following figures describe a principally identical transfer behavior: 	○	○
8)	Controllers with PIDT_2-transmission behavior can due to their complexity only be designed in time domain.	○	○
9)	The relationship between time and frequency domain is defined by $g(t) = \mathcal{L}^{-1}\{G(s)\}$.	○	○

10)	The application of the Laplace transformation for $f(t) = (\frac{1}{2} + cos(3t) - \frac{1}{2}e^{-2t})\mathit{1}(t)$ gives $F(s) = \dfrac{s^3 + 3s^2 + 8}{s(s^2+8)(s+2)}$.	○	○
11)	The system with the transfer function $G(s) = \dfrac{2s-1}{1+s+s^2}$ can be described in time domain by $2\ddot{y} + \dot{y} + y = 2\dot{u} - u$.	○	○
12)	Time delays in the transmission behavior of systems are described in frequency domain by poles and with the same meaning in time domain by higher order derivatives of the input variables.	○	○
13)	The description of a linear time-invariant SISO-system can (independently of the order of the derivatives) always be converted into a frequency domain representation.	○	○
14)	The representation of a linear MIMO-system (A, B, C, D) is always a representation in time domain. A transfer of an A, B, C, D-oriented representation in frequency domain is not possible.	○	○
15)	On the basis of the position of the poles, the I/O-stability of a linear time-invariant SISO system can be determined. The poles of the system are always also eigenvalues of the system, which can be derived e.g. from a state space representation.	○	○

□

1b) (7 Points)
The real and approximated behavior of a system shown in the Bode diagram in the sequel should be analyzed.

- According to which indicators the behavior can be classified as a system with delay time?
- Is the shown behavior those of a minimum phase system (Yes, no, and why)?
- Two equal poles are located at ω_4. After a modification of the plant-controller system, the pole pair is replaced with a single (stable) zero at ω_4. Draw the resulting real and approximated system behavior into the Bode diagram (amplitude and phase).
- Draw qualitatively the polar plot for the frequency range $\omega = 0$ to $\omega = \infty$ based on the modified system featuring the zero instead of the pole pair.

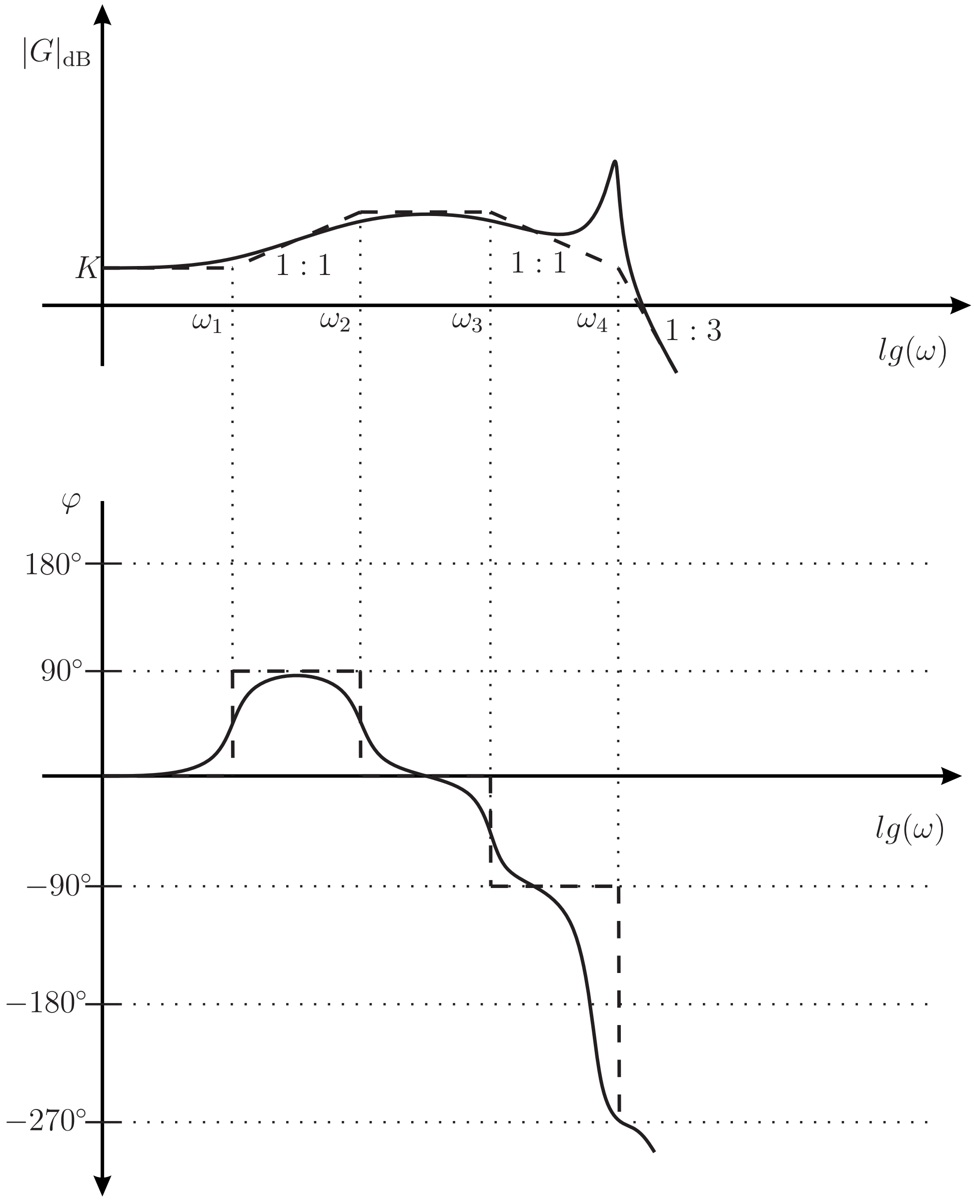


Figure 1.1: Bode diagram

1c) (8 Points)
The disturbance transfer function of a standard control loop is given as

$$G_Z(s) = \frac{K_P(\tilde{T}_1 - s)}{10s^3 + 5s^2 + \tilde{T}_2\ s + 1 + K_P} \quad \text{mit } K_P,\ \tilde{T}_1,\ \tilde{T}_2 > 0.$$

- Determine with the help of the Hurwitz criterion the allowed range of the controller gain K_P (depending on $\tilde{T}_1$ and $\tilde{T}_2$), for which the closed-loop system is asymptotically stable.
- Based on the given constraints, which values for $\tilde{T}_1$ and $\tilde{T}_2$ can be used?
- For which values of $\tilde{T}_1$ and $\tilde{T}_2$ can for the stationary case the best (or desired) behavior of the controller be achieved?

$\square$

$\sum \square$

Aufgabe 2 (60 Points)

2a) (6 Points)
Evaluate the statements in the table below.

No.	Task/Question/Judgement	True	False
1)	A system is defined by the poles $s_{1,2} = -2 \pm j$, $s_3 = 3$, and $s_4 = 0$. The I/O-behavior of the system is stable.	◯	◯
2)	A system with integral behavior has to be controlled stationary accurate. To achieve this goal, for example, an integral part can be integrated in the feedback.	◯	◯
3)	Delay time elements affect the phase by an additional phase delay of $\Delta\varphi_{\text{tot}} = -\omega T_{\text{t}}$, with T_{t} defined as inertia of the system.	◯	◯

☐

2b) (3 Points)
The transfer function

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

has the following poles and zeros:

- ◯ $s_{\mathrm{p}_{1,2}} = -1 \pm j$
  $s_{\mathrm{p}_3} = 1$
  $s_{\mathrm{n}_1} = -2$
  $s_{\mathrm{n}_2} = -3$
- ◯ $s_{\mathrm{p}_{1,2,3}} = -1$
  $s_{\mathrm{n}_1} = -2$
  $s_{\mathrm{n}_2} = -3$
- ◯ $s_{\mathrm{p}_1} = 1$
  $s_{\mathrm{p}_{2,3}} = -1$
  $s_{\mathrm{n}_1} = 3$
  $s_{\mathrm{n}_2} = -2$
- ◯ $s_{\mathrm{n}_1} = 2$
  $s_{\mathrm{n}_2} = -3$.
  $s_{\mathrm{p}_{1,2,3}} = -1$

☐

2c) (8 Points)
The measurement of the transfer behavior of an open-loop system is shown in the figure below as Bode diagram. (Beware of the scaling)

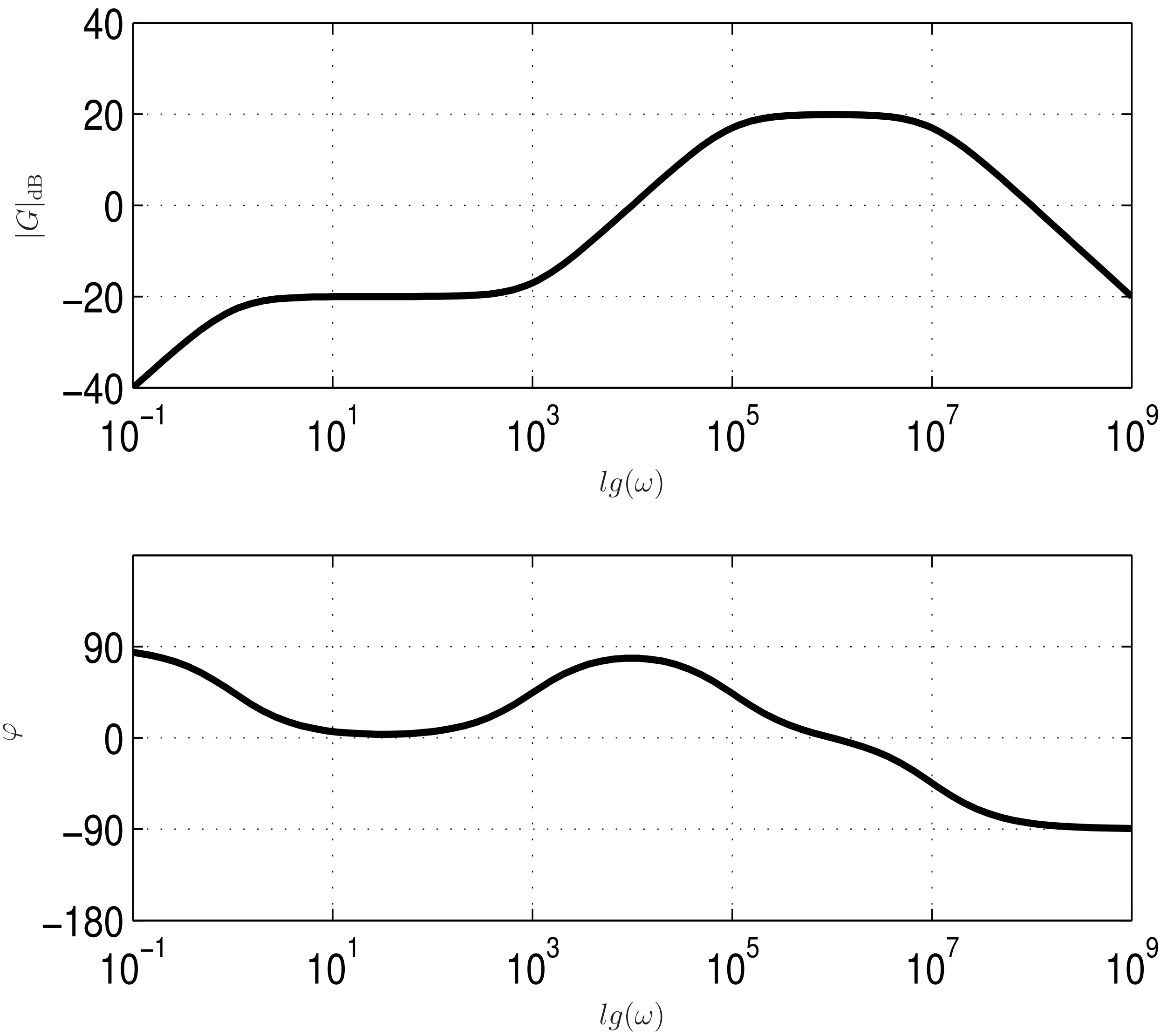


Figure 2.1: Bode diagramm

What can be concluded from the diagram?

No.	Task/Question/Judgement	True	False
1)	The system behavior is integral.	◯	◯
2)	The system behavior is nonlinear.	◯	◯
3)	The margin of the phase at the larger crossover frequency of the system is larger than 90 degrees.	◯	◯
4)	The closed-loop system is stable.	◯	◯

☐

2d) (8 Points)

A system with the transfer function

$$G(s) = \frac{K}{s^2 + Ds - 1}$$

should be controlled 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 has a steady-state accuracy error regarding the reference behavior of $e(t \to \infty) = \frac{KK_{\mathrm{R}}}{KK_{\mathrm{R}} - 1}$.	○	○
2)	A differential part for $G(s)$ leads to a stationary behavior without steady-state error and perfect compensation of disturbances.	○	○
3)	The parameter D can affect the stability of the closed-loop system.	○	○
4)	The parameter K affects the vibrational behavior of the closed-loop system.	○	○

□

For the following tasks, a control loop with the transfer behavior of the plant

$G_S(s) = \dfrac{s\tilde{T}+1}{s(s^2+2s+2)}$ and the transfer behavior of the controller

$G_R(s) = \dfrac{K_R}{s\tilde{T}_R+1}$ is defined.

2e) (3 Points)
The open control loop has the following poles and zeros:

- ○ $s_{p_1} = 0$
  $s_{p_2} = -\frac{1}{\tilde{T}_R}$
  $s_{p_{3,4}} = -\frac{1}{\tilde{T}} \pm j$
  $s_{n_1} = -1$
- ○ $s_{p_1} = 0$
  $s_{p_2} = -\frac{1}{\tilde{T}_R}$
  $s_{p_{3,4}} = -1 \pm j$
  $s_n = -\frac{1}{\tilde{T}}$
- ○ $s_{p_{1,2}} = 0$
  $s_{p_{3,4}} = -1 \pm j$
- ○ $s_{n_1} = 0$
  $s_{n_2} = -\frac{1}{\tilde{T}}$
  $s_{n_{3,4}} = -1 \pm j$.
  $s_{p_1} = -\frac{1}{\tilde{T}_R}$

□

2f) (16 Points)
Please answer the following questions based on the above given plant with the transfer function $G_\mathrm{S}(s)$ and those of the controller $G_\mathrm{R}(s)$.

No.	Task/Question/Judgement	True	False
1)	The closed-loop system can not become unstable (K_R, $\tilde{T}_\mathrm{R}$, $\tilde{T} > 0$).	○	○
2)	Depending on the parameters K_R, $\tilde{T}_\mathrm{R}$, $\tilde{T}$ the damping of the modes able to vibrate can be adjusted.	○	○
3)	For at least one of the values K_R, $\tilde{T}_R$, $\tilde{T} \to \infty$ the closed-loop system becomes unstable.	○	○
4)	The open-loop system is boundary stable.	○	○
5)	The closed-loop system is boundary stable.	○	○
6)	Adding a pole $G_\mathrm{R2}(s) = \frac{1}{1+T_\mathrm{P1}\ s}$ with $T_\mathrm{P1} << \tilde{T}$ does not affect the stability properties in general ($G^*_\mathrm{R}(s) = G_\mathrm{R}(s)\ G_\mathrm{R2}(s)$).	○	○
7)	The open-loop system with $G^*_\mathrm{R}(s) = G_\mathrm{R}(s)\ G_\mathrm{R2}(s)$ is asymptotically stable.	○	○
8)	Adding an additional pole $G_\mathrm{R3}(s) = \frac{1}{1+T_\mathrm{P2}\ s}$ with $T_\mathrm{P2} > \tilde{T}$ allows principally the realization of an obviously vibration-free ($D < \frac{\sqrt{2}}{2}$) behavior ($G^{**}_\mathrm{R}(s) = G_\mathrm{R}(s)\ G_\mathrm{R2}(s)\ G_\mathrm{R3}(s)$).	○	○

2g) (6 Points)
A system to be controlled has the structure shown below.

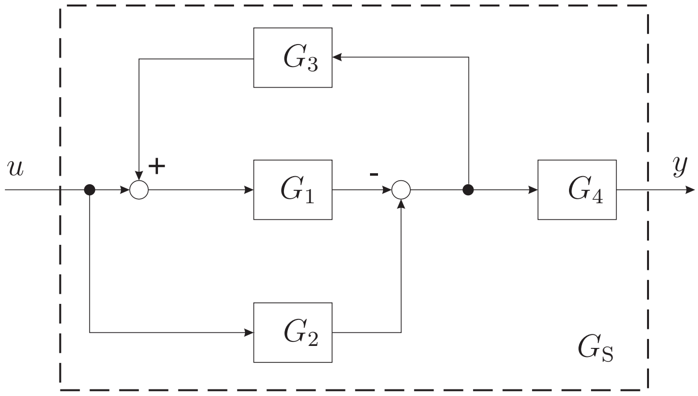


Figure 2.2: System to be controlled

In the following, the transfer behavior of the system is assumed as

$$G_S(s) = \frac{K\ s\ (s+10)}{(s+2)}$$

To control the system, a controller with the transfer function

$G_R(s) = \frac{K_R}{s^2}$ is available.

Specify in detail the numerical amplitude behavior $|G_O(j\omega)|$ and the numerical phase behavior $\varphi_O(\omega)$ for the open-loop system $G_O(s) = G_S(s)\ G_{R(s)}$.

2h) (10 Points)
An open-loop system $G_{O1}(s)$ with a PDT_2-behavior is given. Sketch all the polar plots of the three systems defined by the following pole/zero distributions and evaluate the stability of the closed-loop system (negative feedback) of each using the simplified Nyquist criterion.

I:	II:	III:
$s_{n_1} = -1$	$s_{n_1} = -10$	$s_{n_1} = -100$
$s_{p_1} = -10$	$s_{p_1} = -1$	$s_{p_1} = -1$
$s_{p_2} = -100$	$s_{p_2} = -100$	$s_{p_2} = -10$

□

$\sum$ □