

Chapter 9

Design via Root Locus

Figure 9.1

- a.** Sample root locus, showing possible design point via gain adjustment (A) and desired design point that cannot be met via simple gain adjustment (B);
- b.** responses from poles at A and B

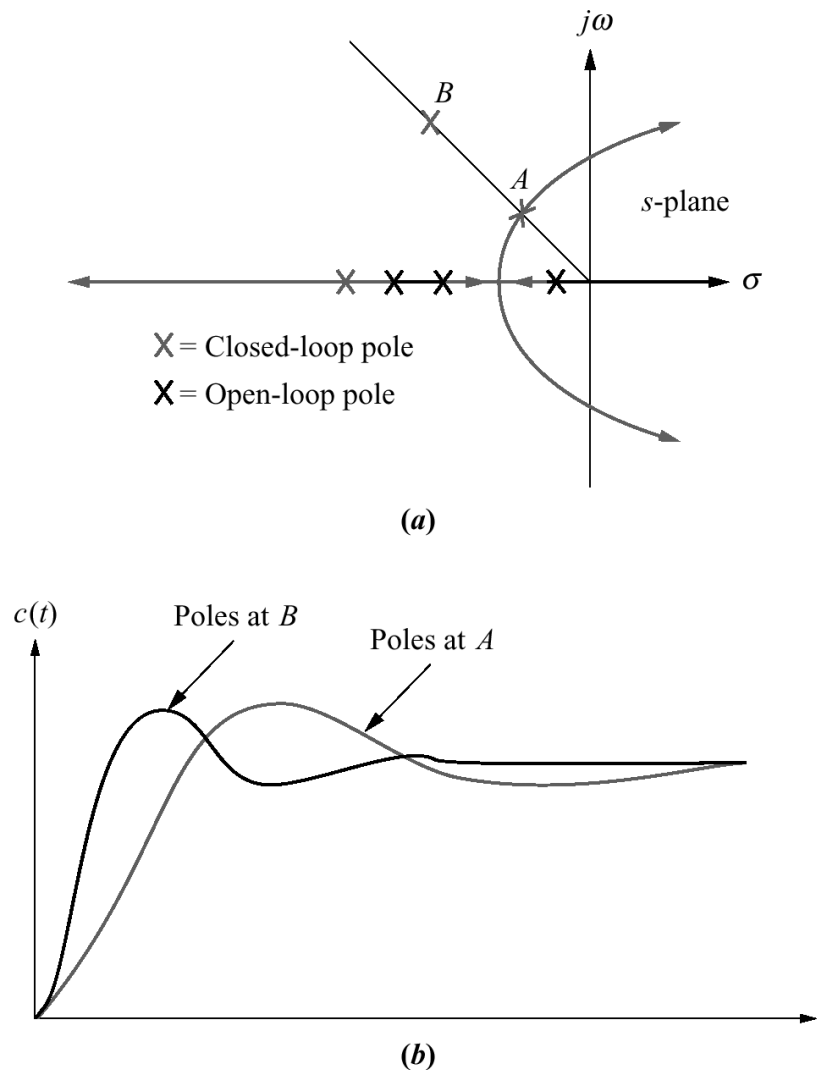


Figure 9.2
Compensation
techniques:
a. cascade;
b. feedback

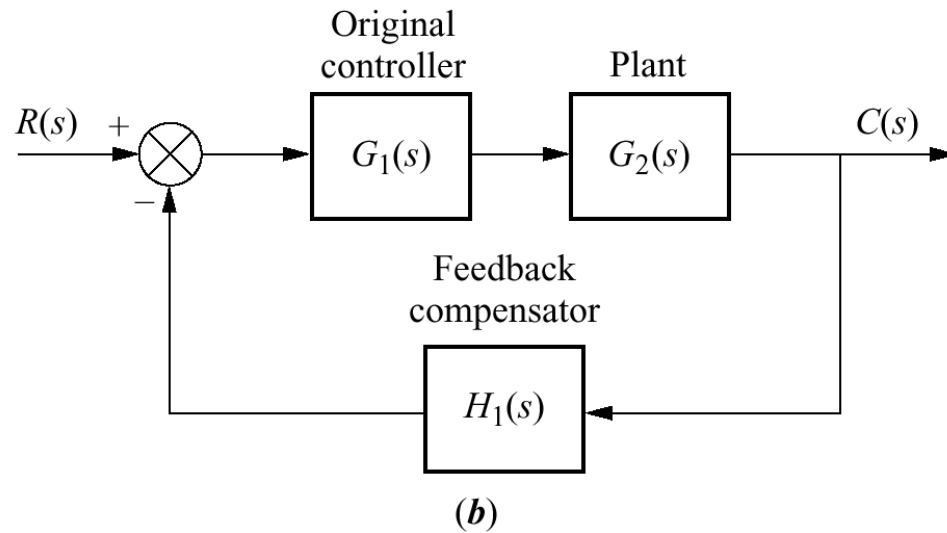
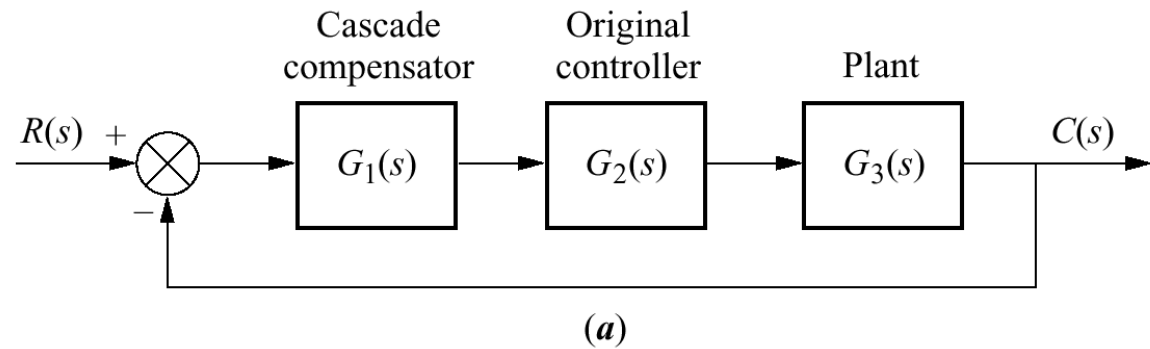


Figure 9.3

Pole at A is:

a. on the root locus without compensator;

b. not on the root locus with compensator pole added;
(figure continues)

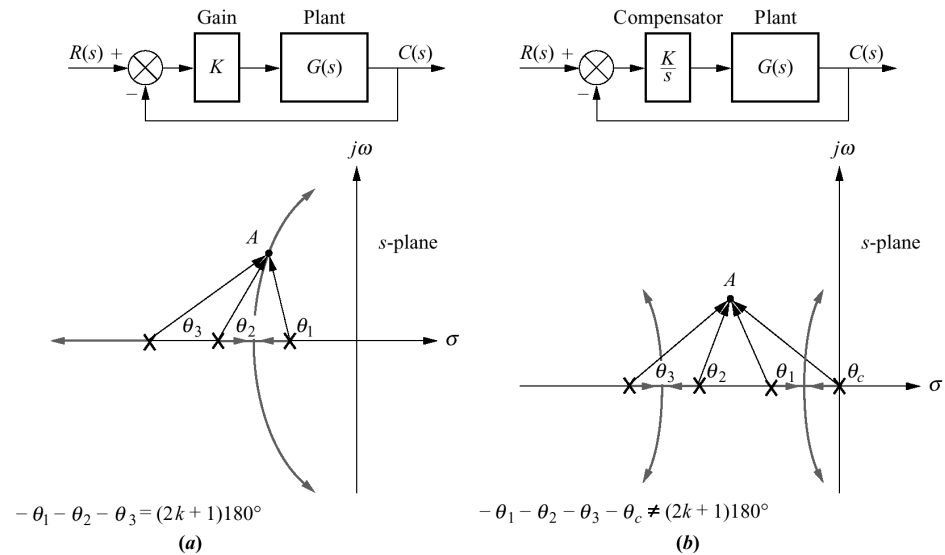


Figure 9.3*(continued)*

c. approximately on the root locus with compensator pole and zero added

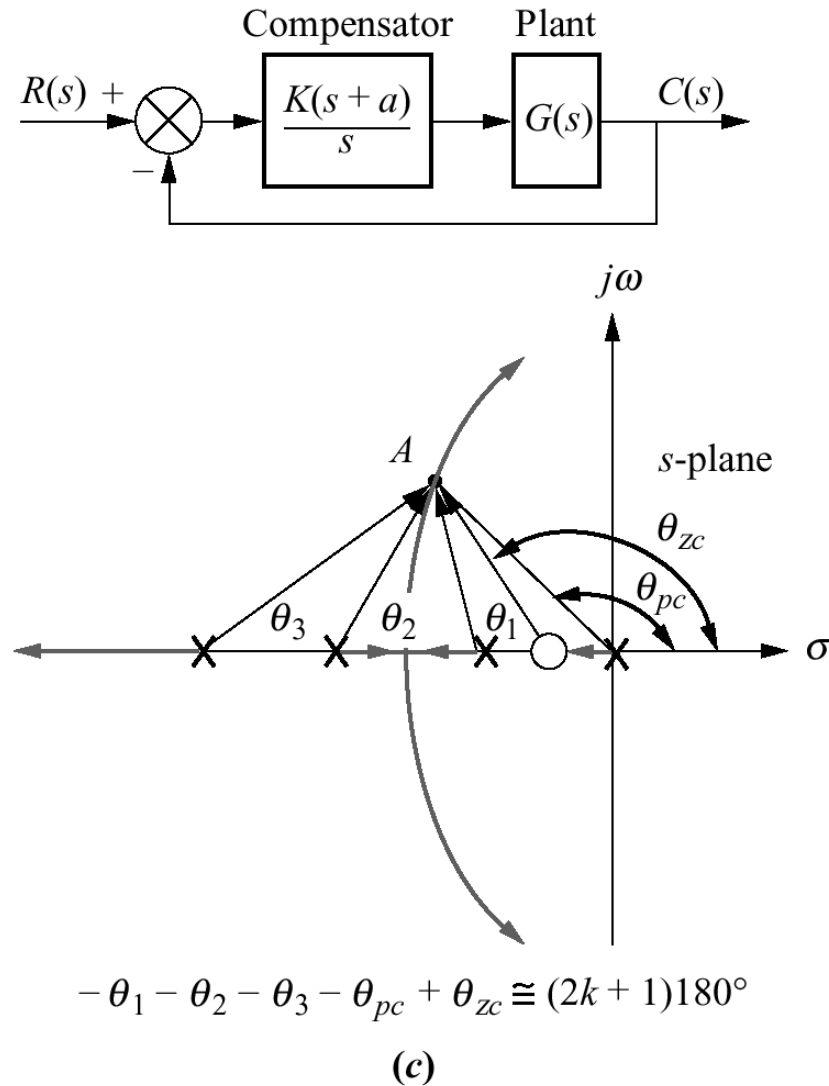


Figure 9.4

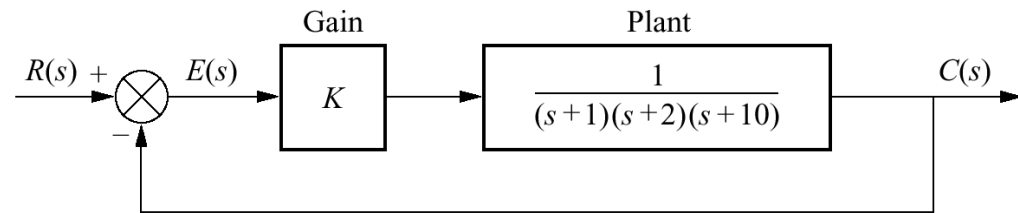
Closed-loop system for
Example 9.1:

a. before

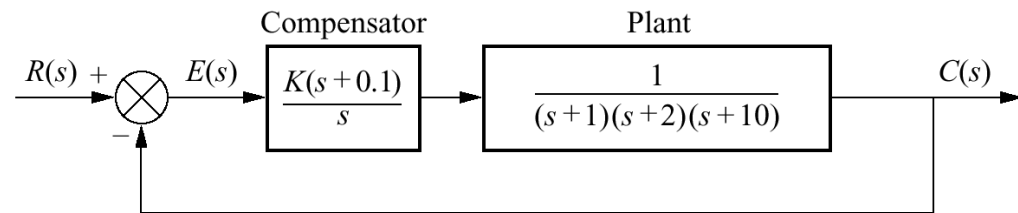
compensation;

b. after ideal integral

compensation



(a)



(b)

Figure 9.5
Root locus for
uncompensated
system of
Figure 9.4(a)

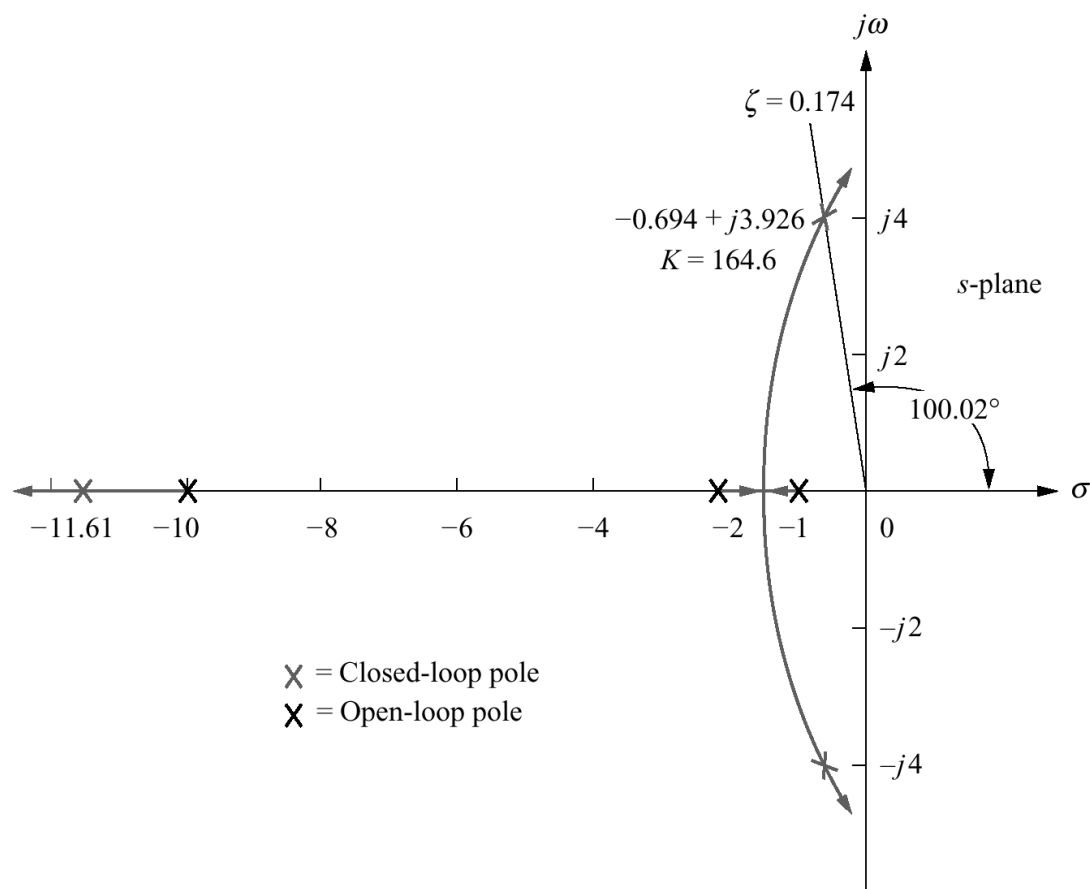


Figure 9.6
Root locus for
compensated
system
of Figure 9.4(b)

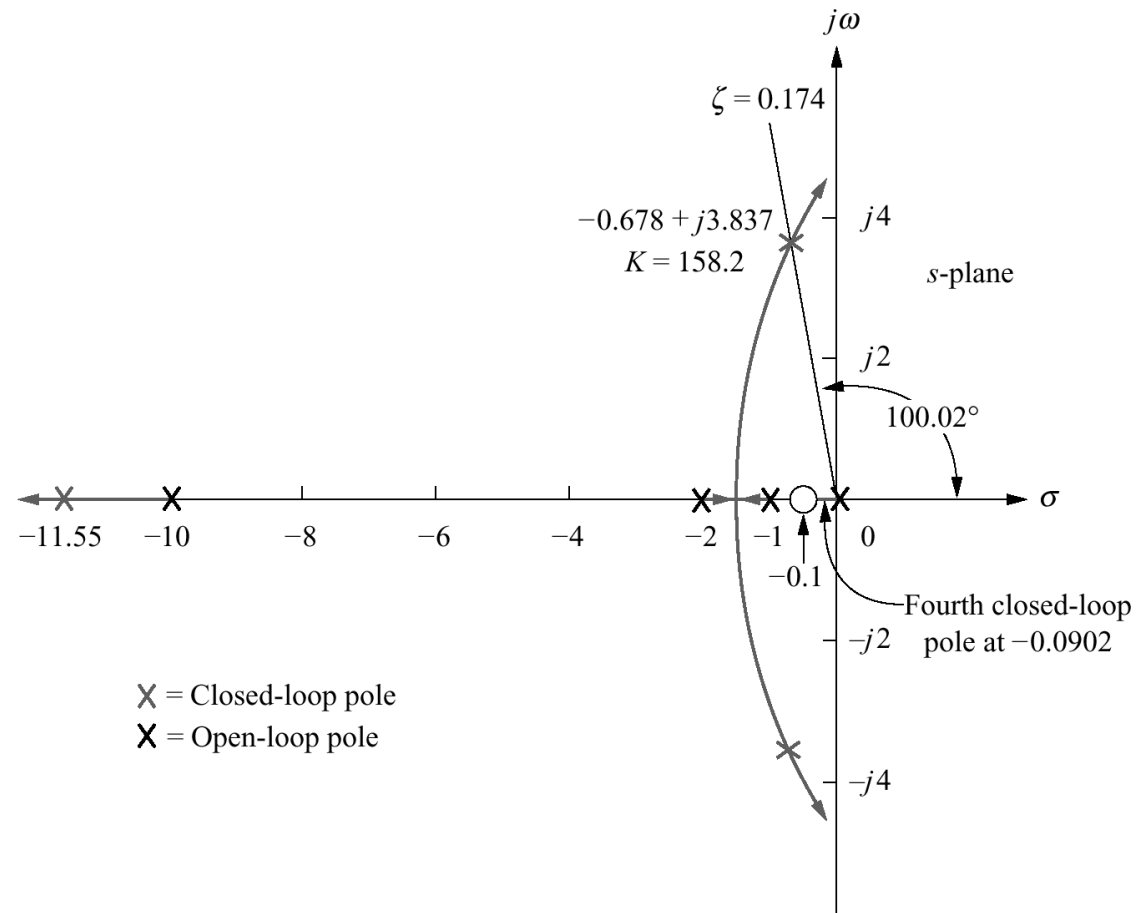


Figure 9.7

Ideal integral compensated system response and the uncompensated system response of Example 9.1

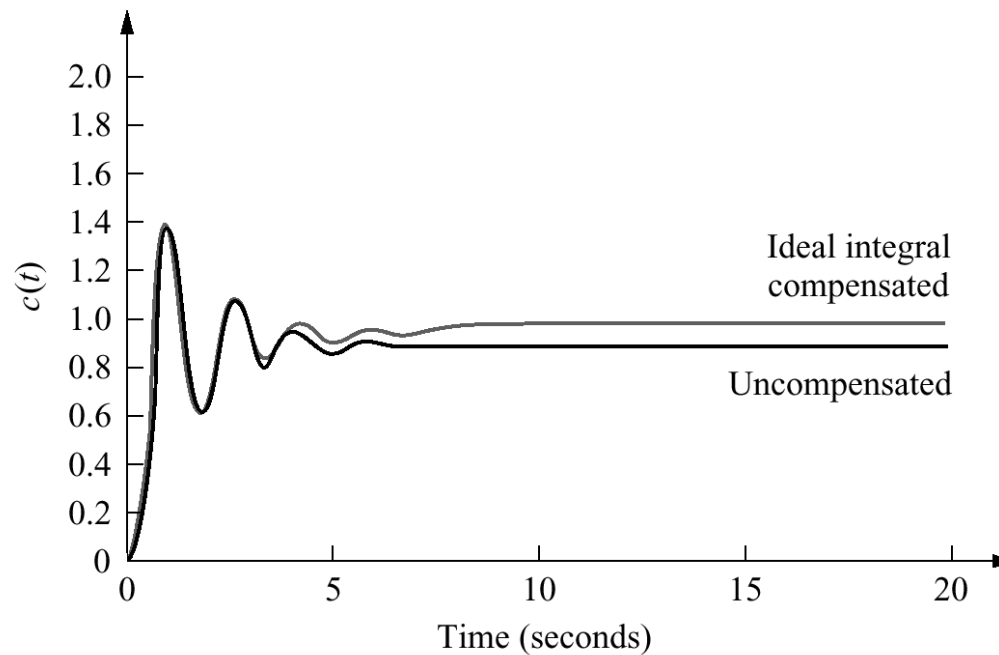


Figure 9.8
PI controller

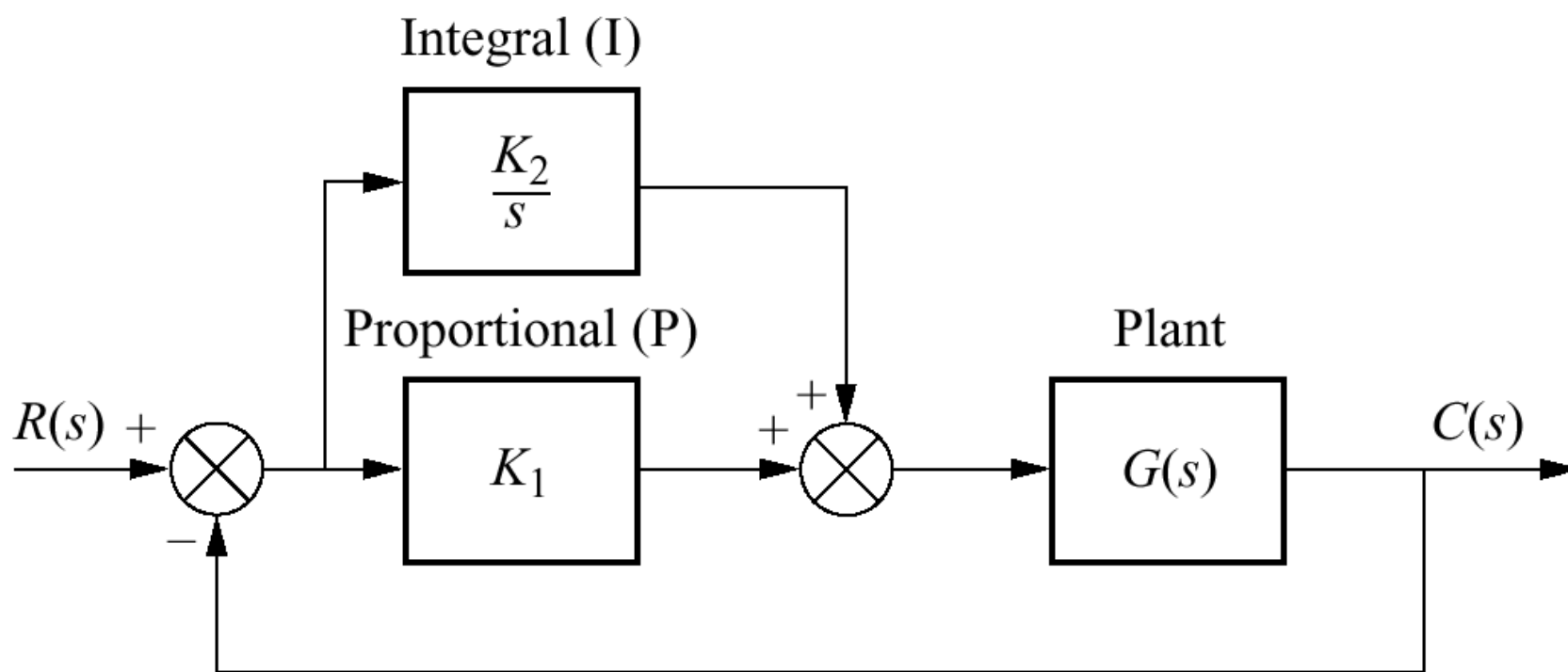


Figure 9.9

- a.** Type 1 uncompensated system;
b. Type 1 compensated system;
c. compensator pole-zero plot

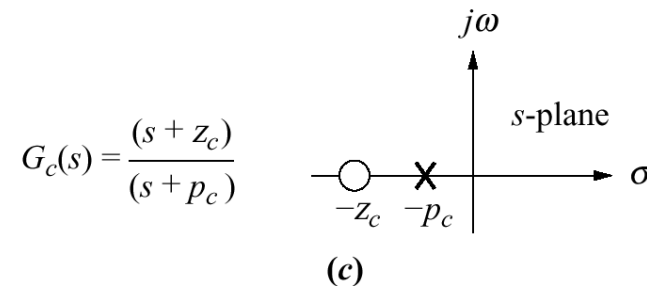
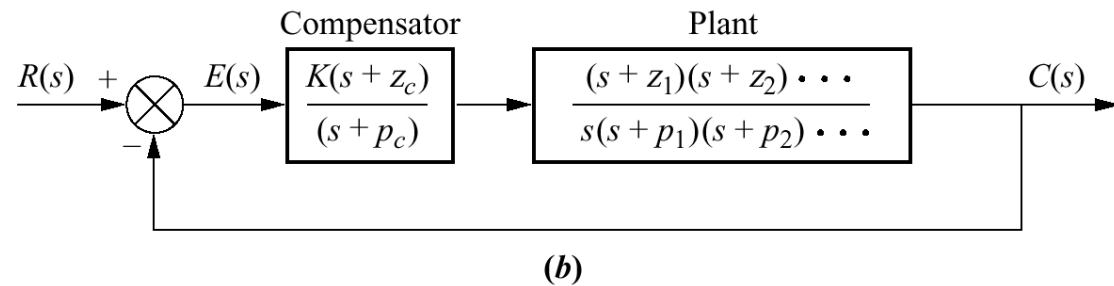
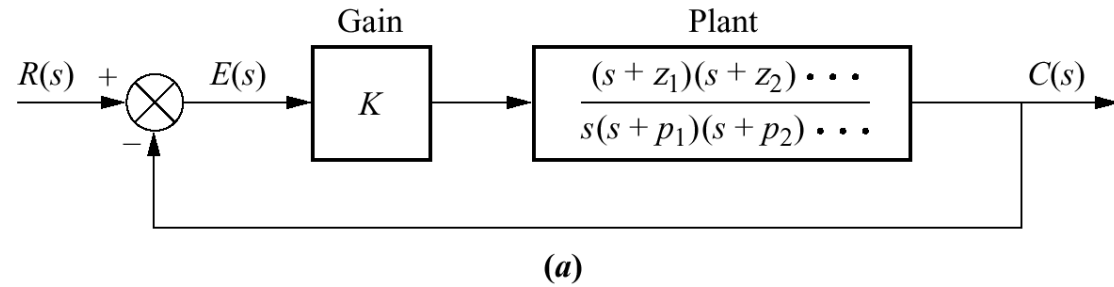


Figure 9.10

Root locus:

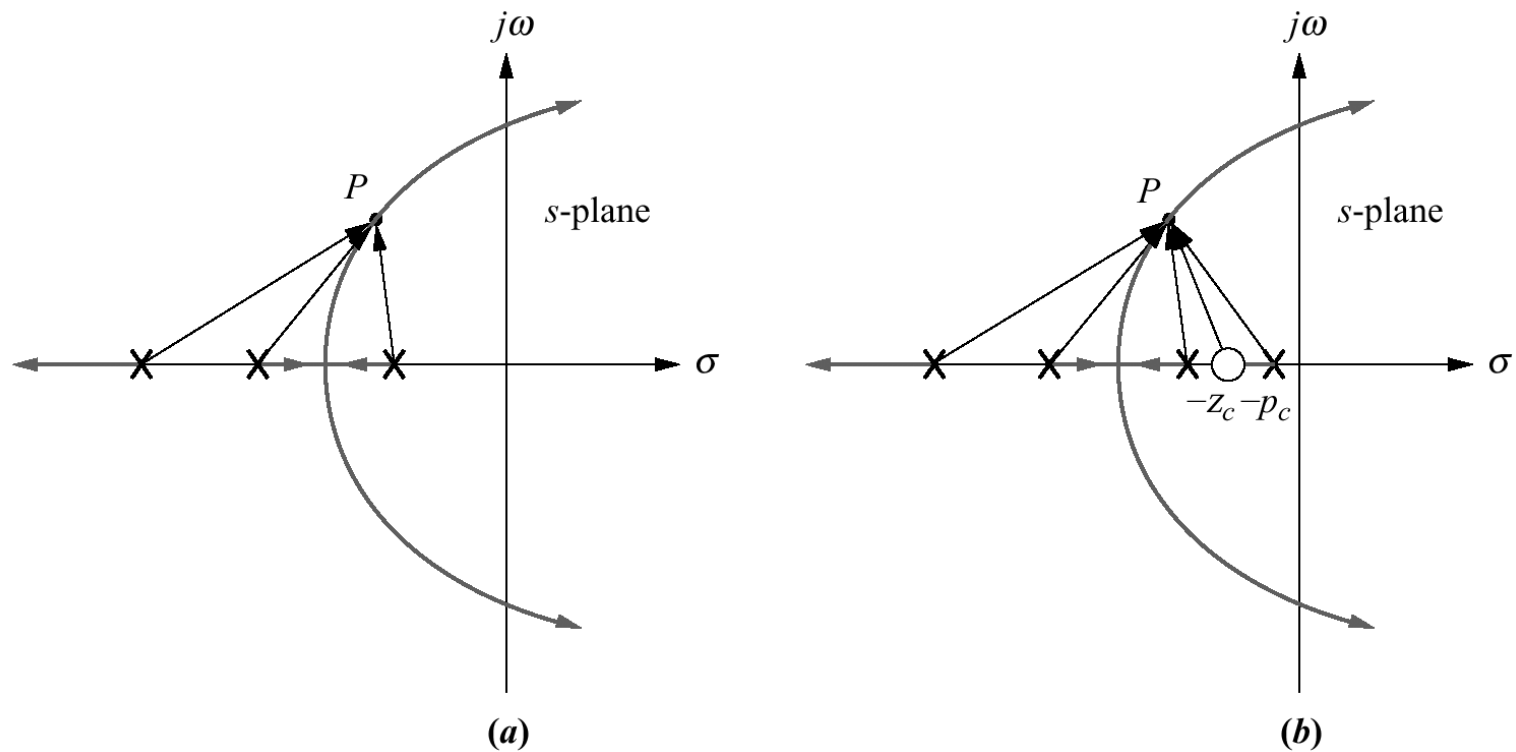
a. before lag compensation;**b.** after lag compensation

Figure 9.11
Compensated system
for Example 9.2

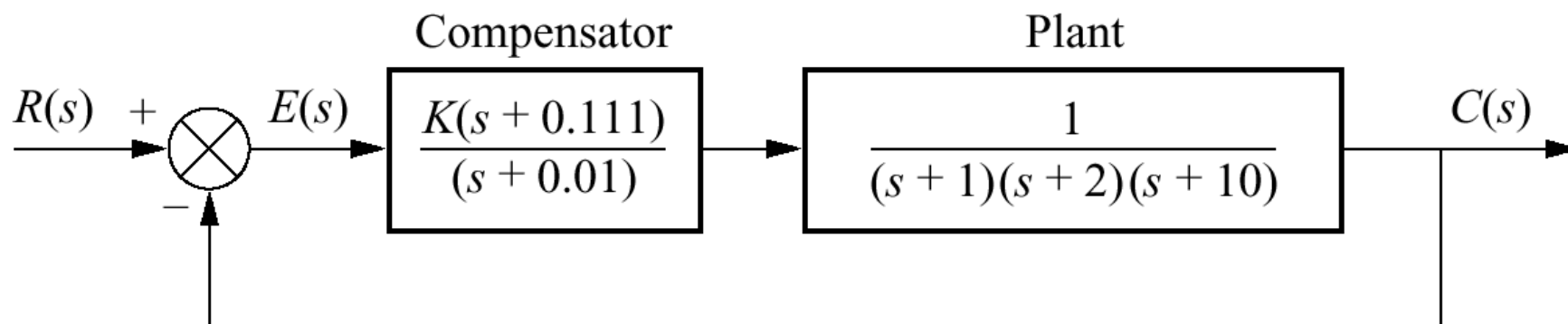


Figure 9.12
Root locus for
compensated system
of Figure 9.11

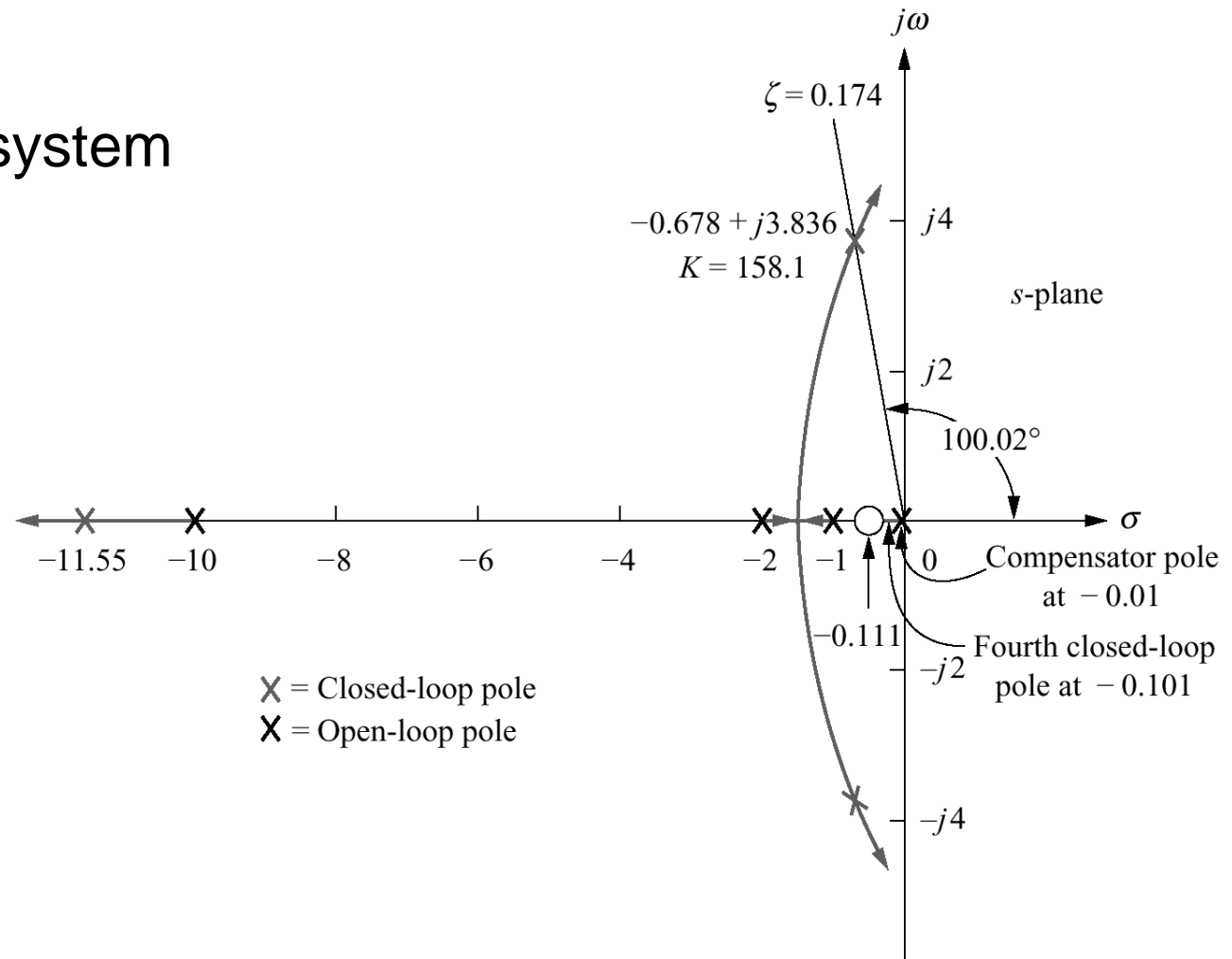


Figure 9.13

Step responses of uncompensated and lag-compensated systems for Example 9.2

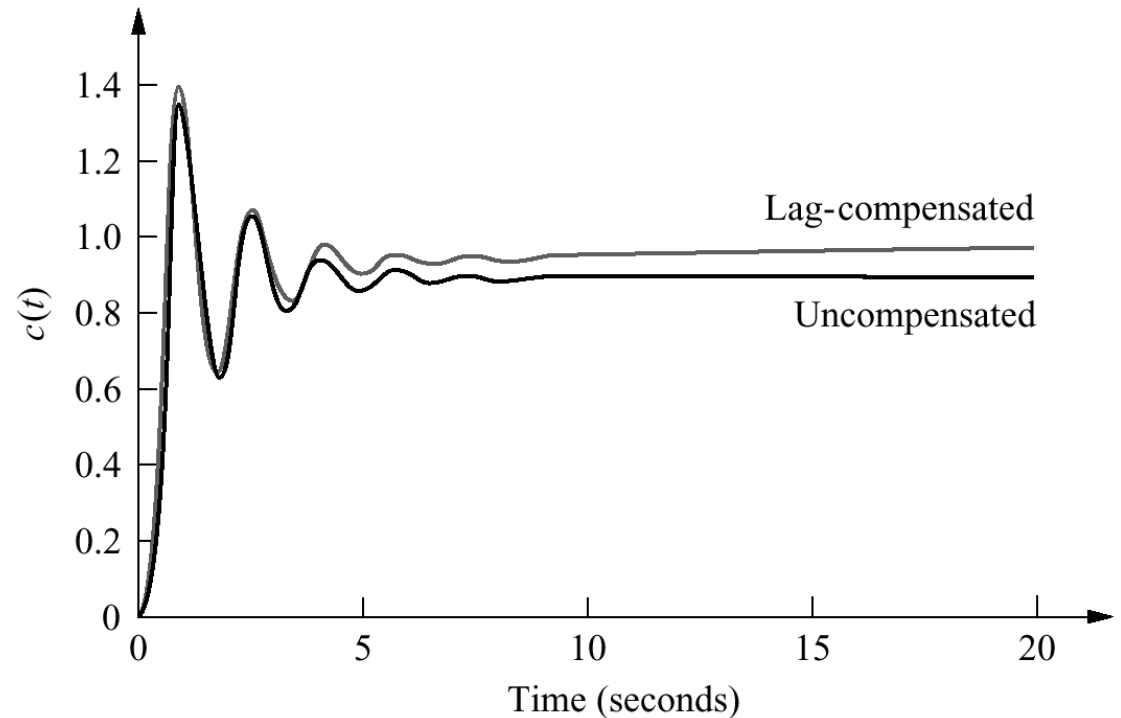


Figure 9.14
Step responses of
the system for
Example 9.2 using
different lag
compensators

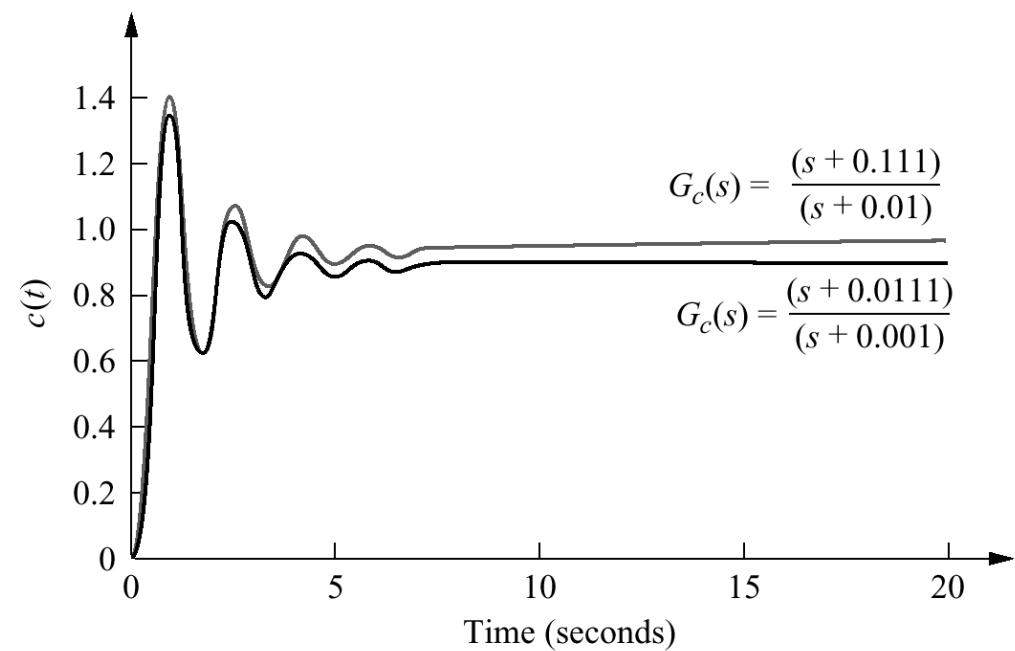


Figure 9.15

Using ideal derivative compensation:

a. uncompensated;

b. compensator zero at -2 ;

(figure continues)

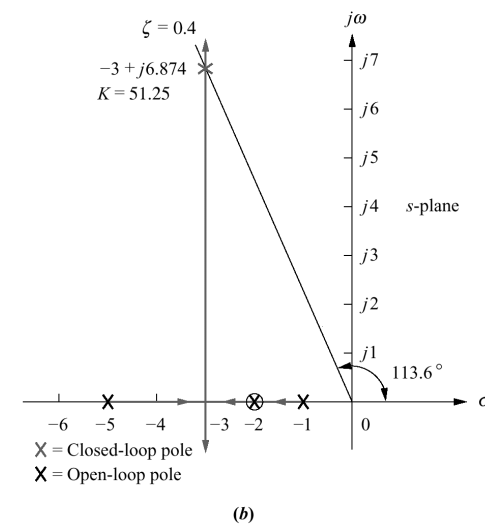
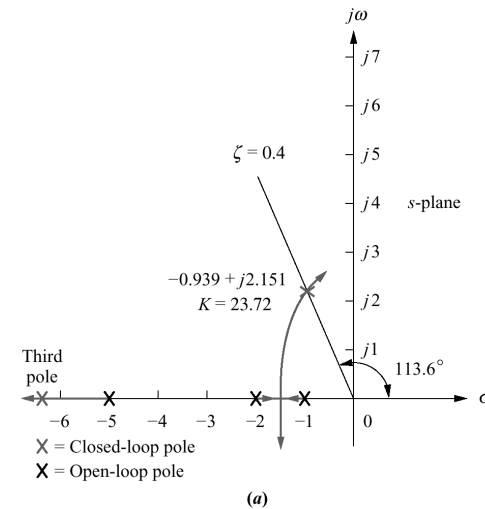


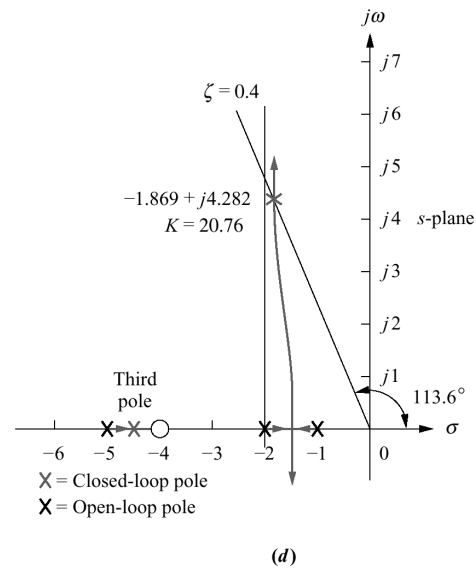
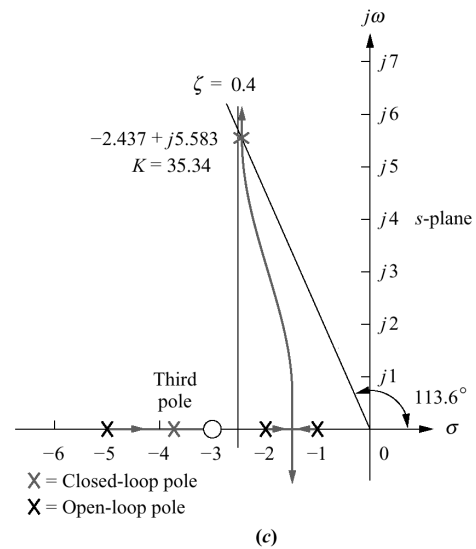
Figure 9.15**(continued)****c.** compensator
zero at -3 ;**d.** compensator
zero at -4 

Figure 9.16
Uncompensated system
and ideal derivative
compensation
solutions
from Table 9.2

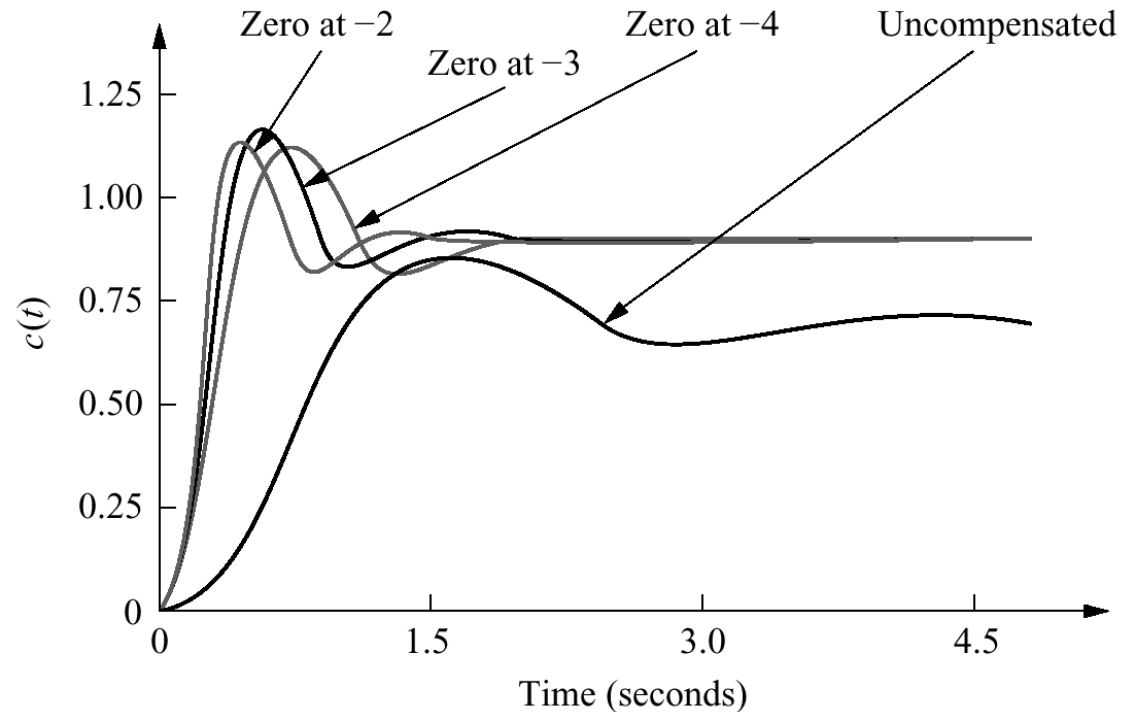


Figure 9.17
Feedback
control system
for Example 9.3

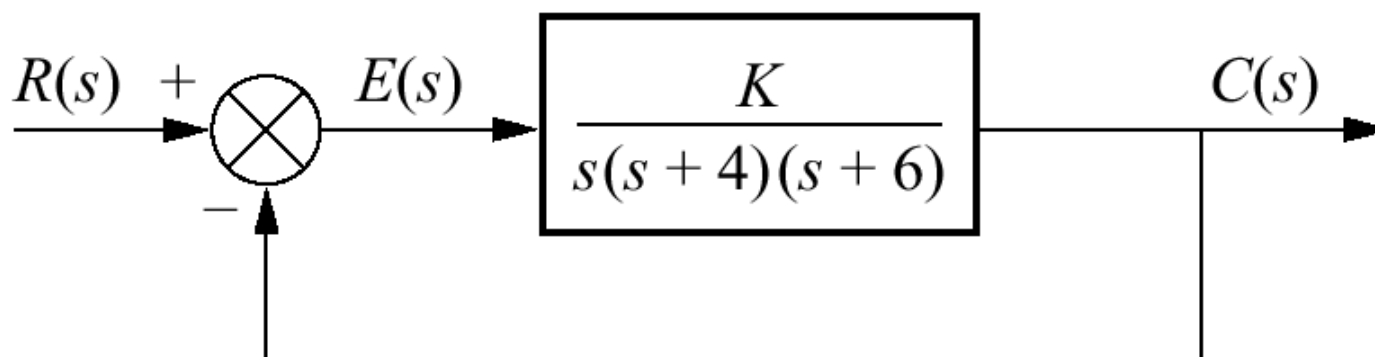


Figure 9.18
Root locus for
uncompensated
system shown in
Figure 9.17

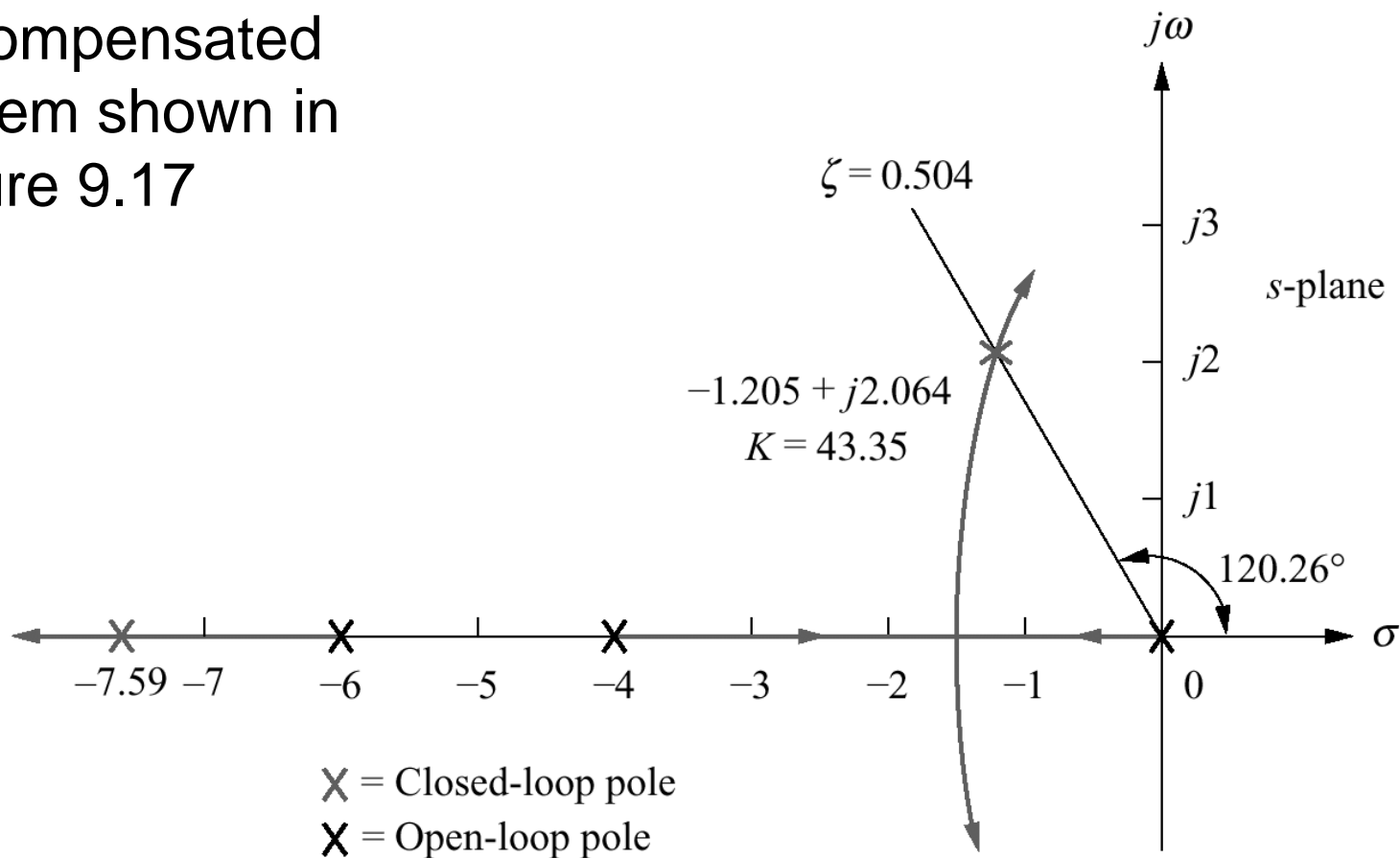


Figure 9.19
Compensated
dominant pole
superimposed over
the uncompensated
root locus for
Example 9.3

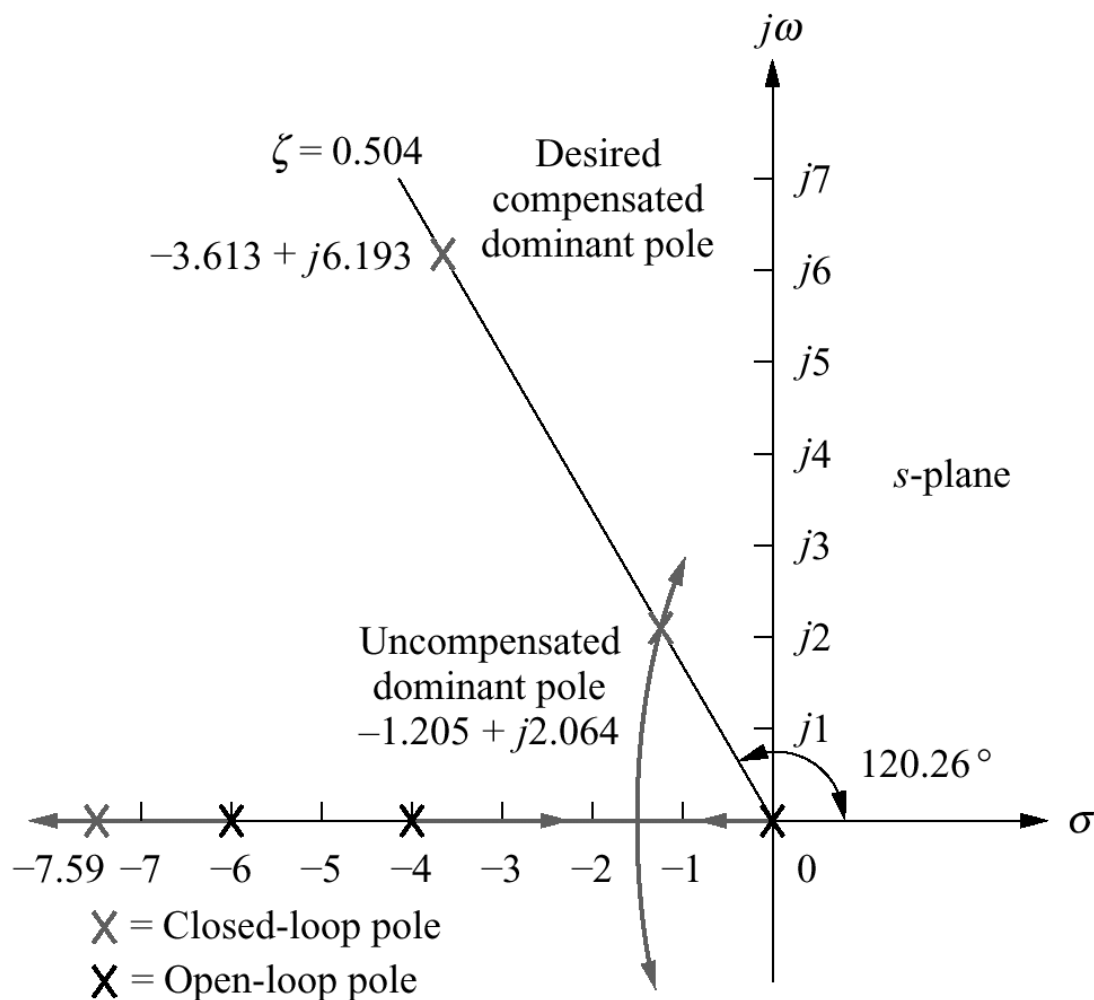


Figure 9.20
Evaluating the
location
of the compensating
zero for Example 9.3

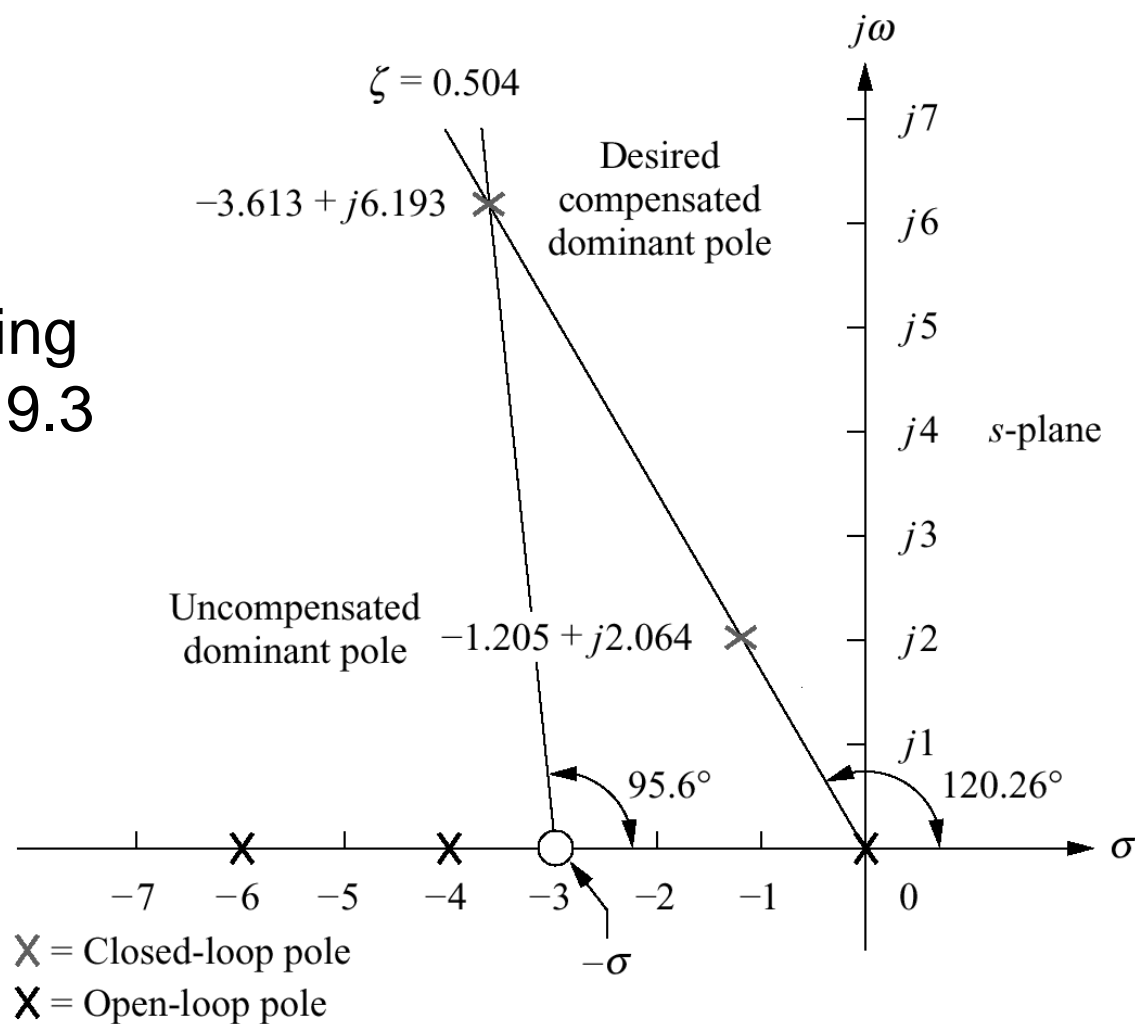


Figure 9.21
Root locus for the
compensated system
of Example 9.3

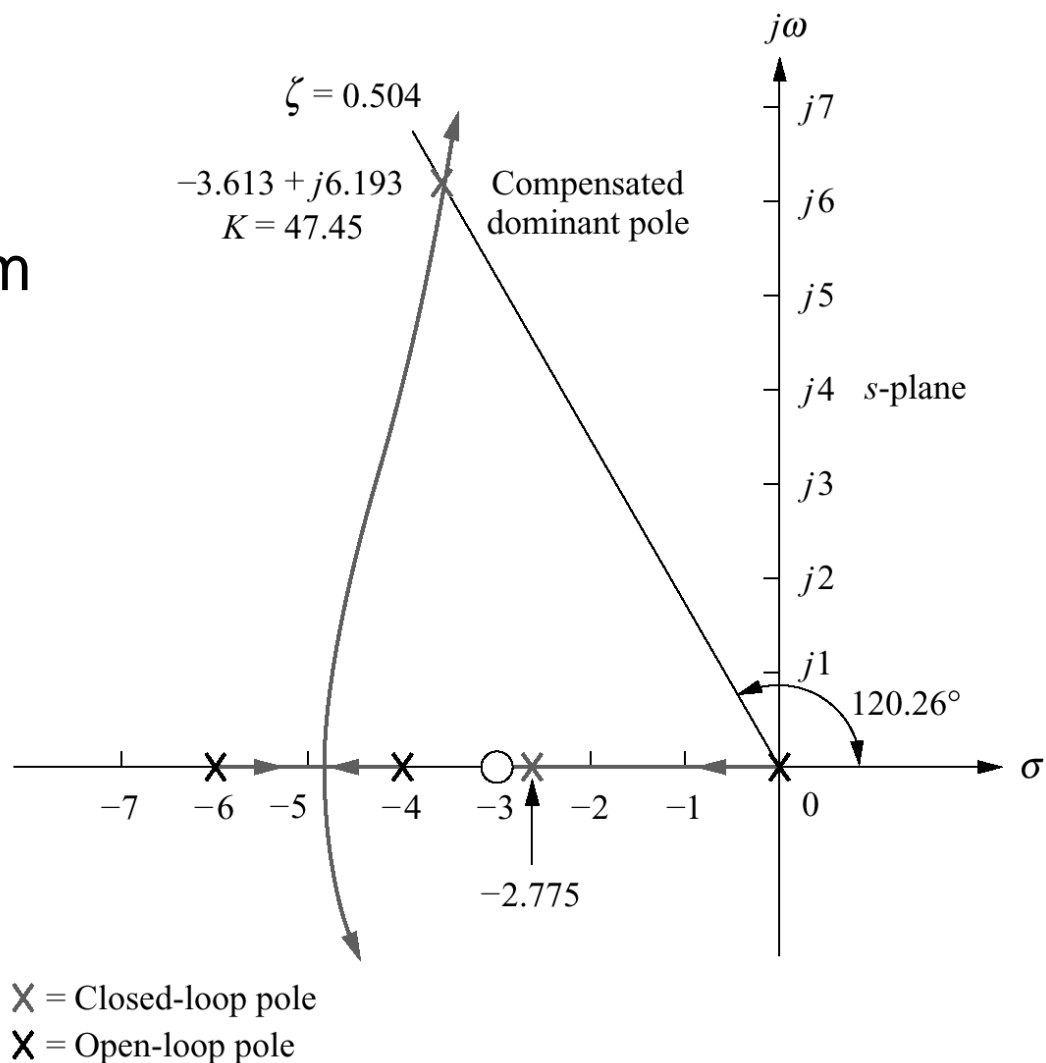


Figure 9.22

Uncompensated and compensated system step responses of Example 9.3

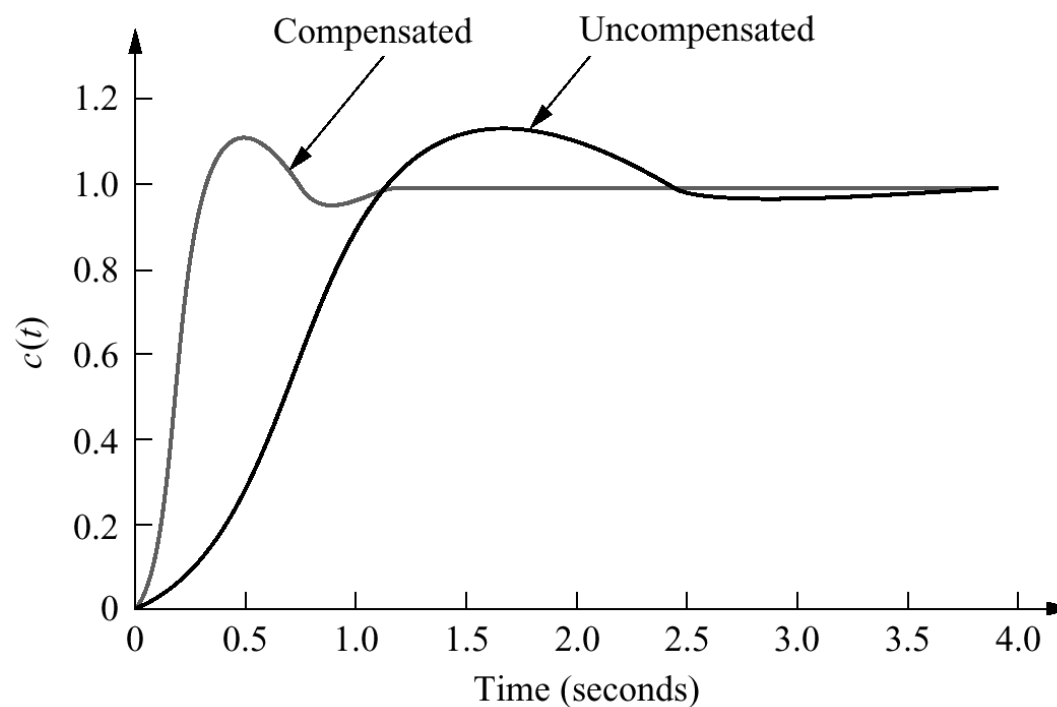


Figure 9.23
PD controller

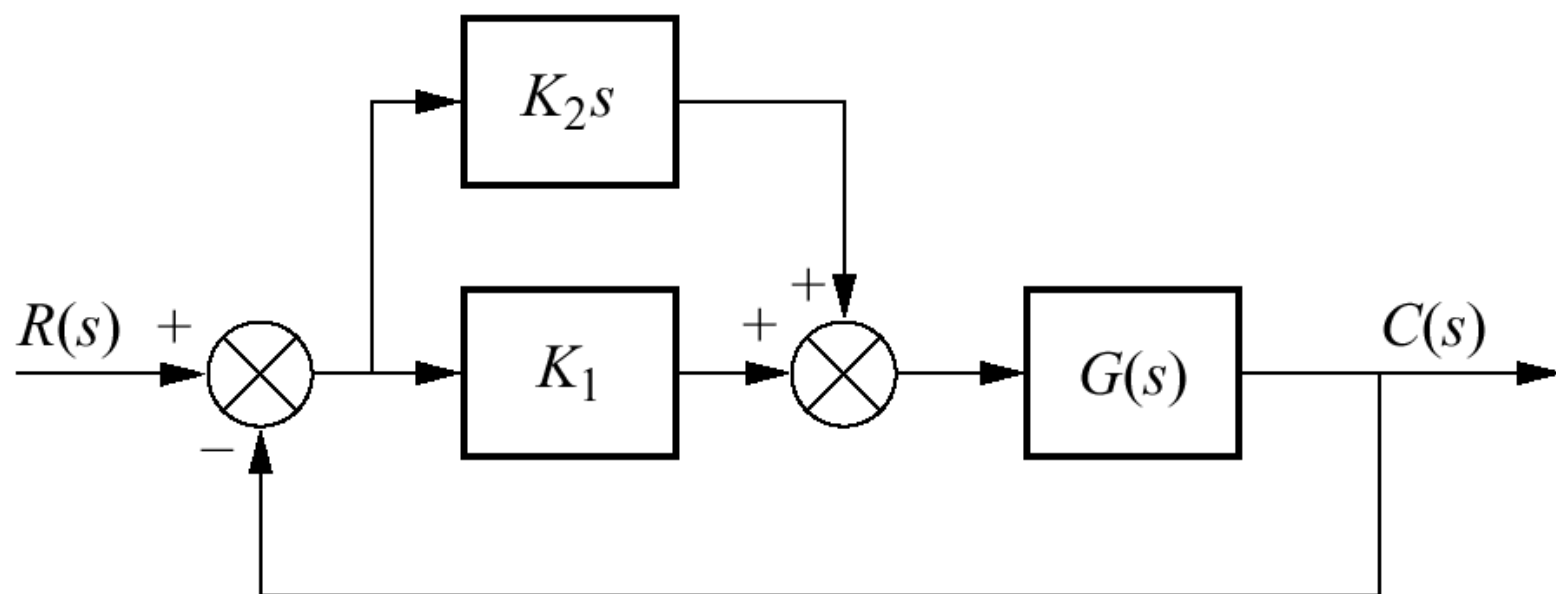


Figure 9.24
Geometry of lead compensation

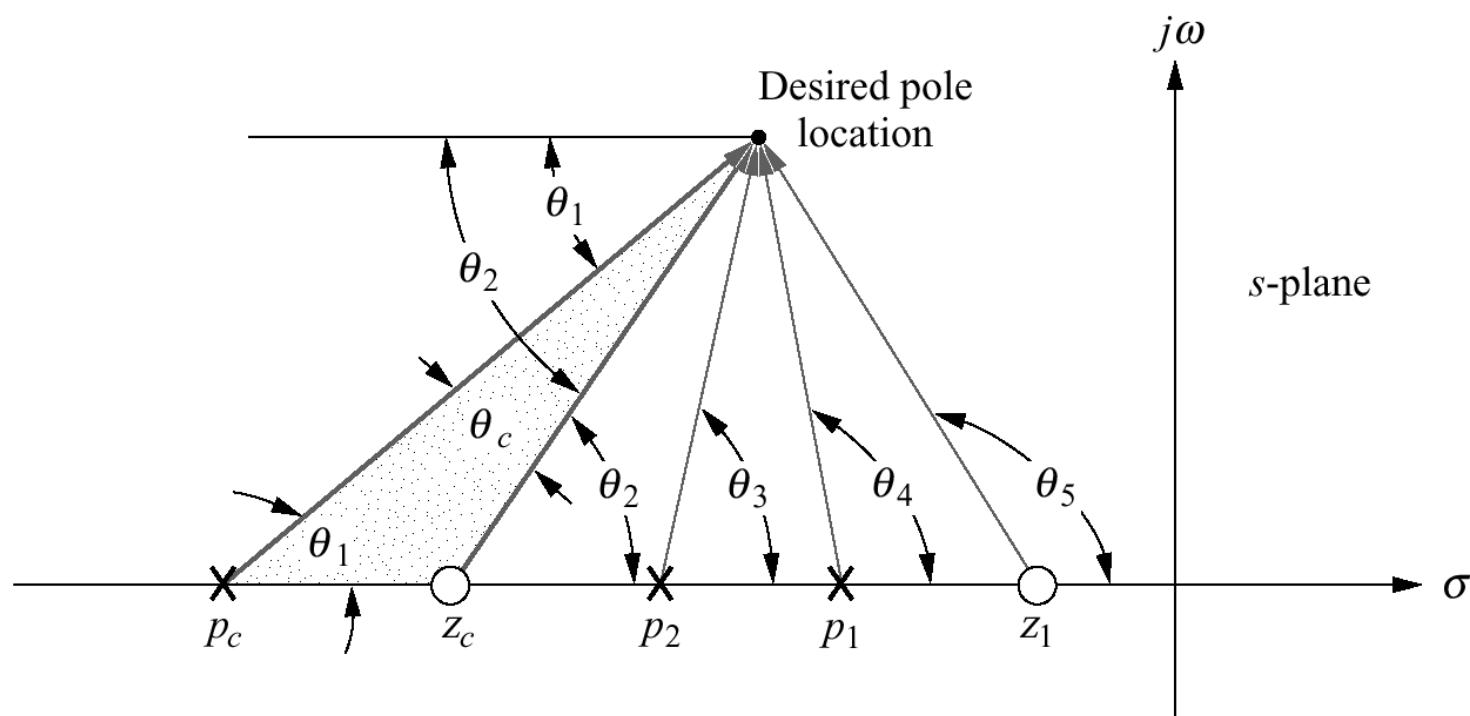


Figure 9.25
Three of the infinite
possible lead
compensator solutions

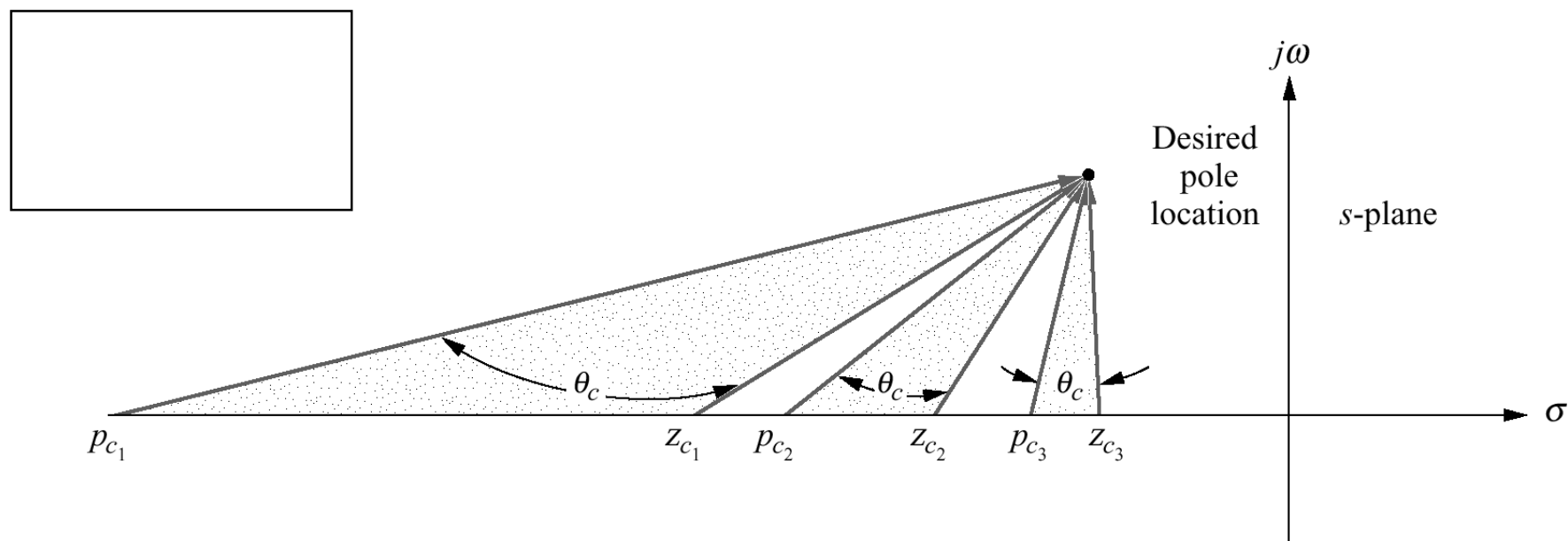


Figure 9.26

Lead compensator design, showing evaluation of uncompensated and compensated dominant poles for Example 9.4

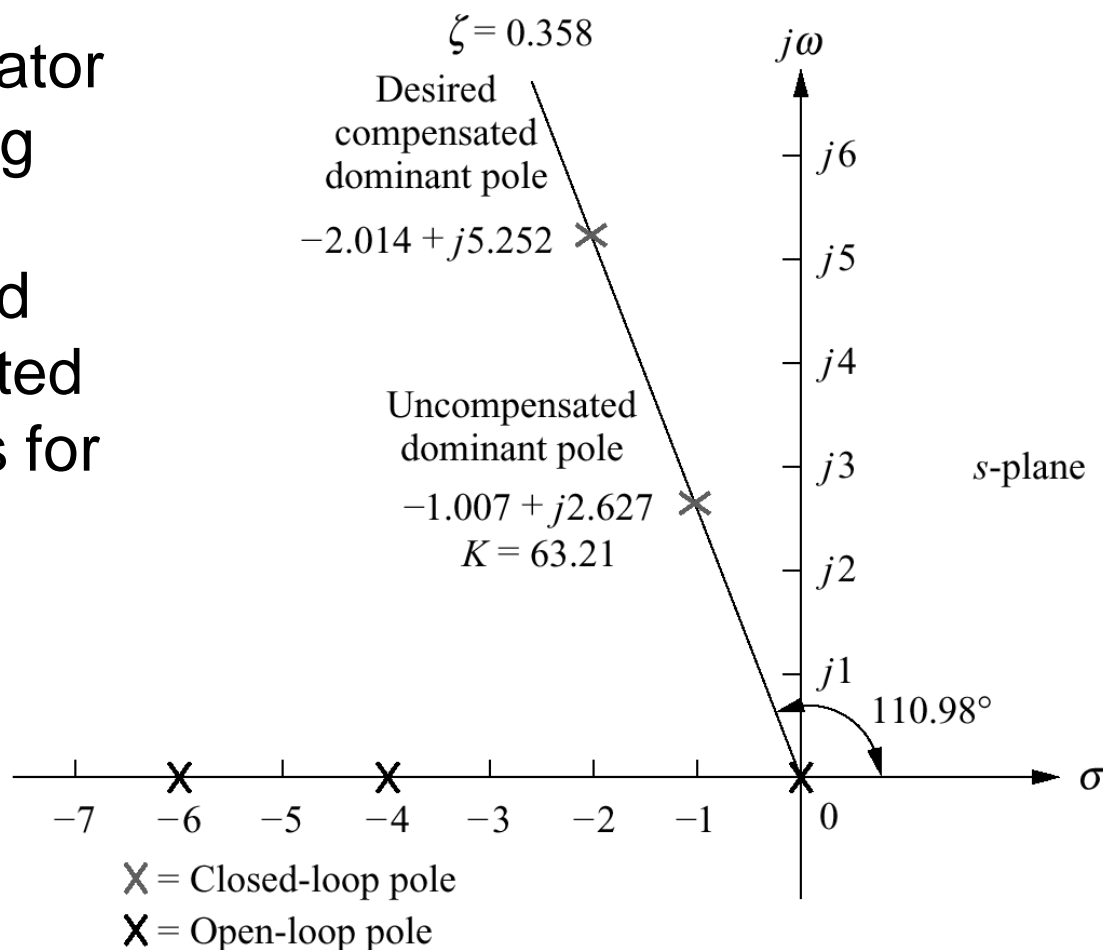
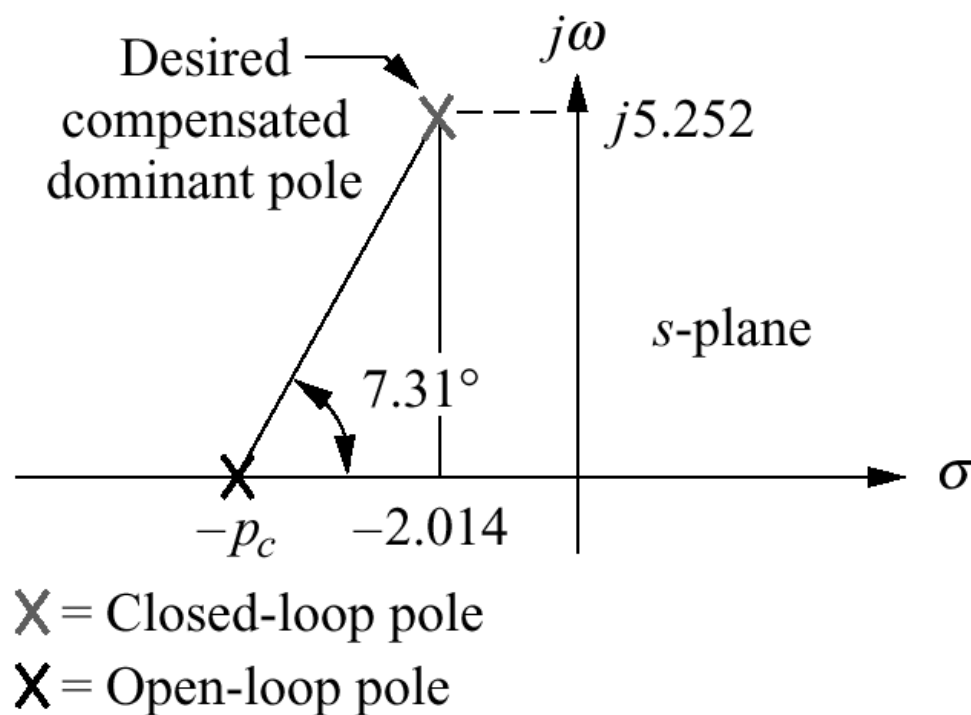


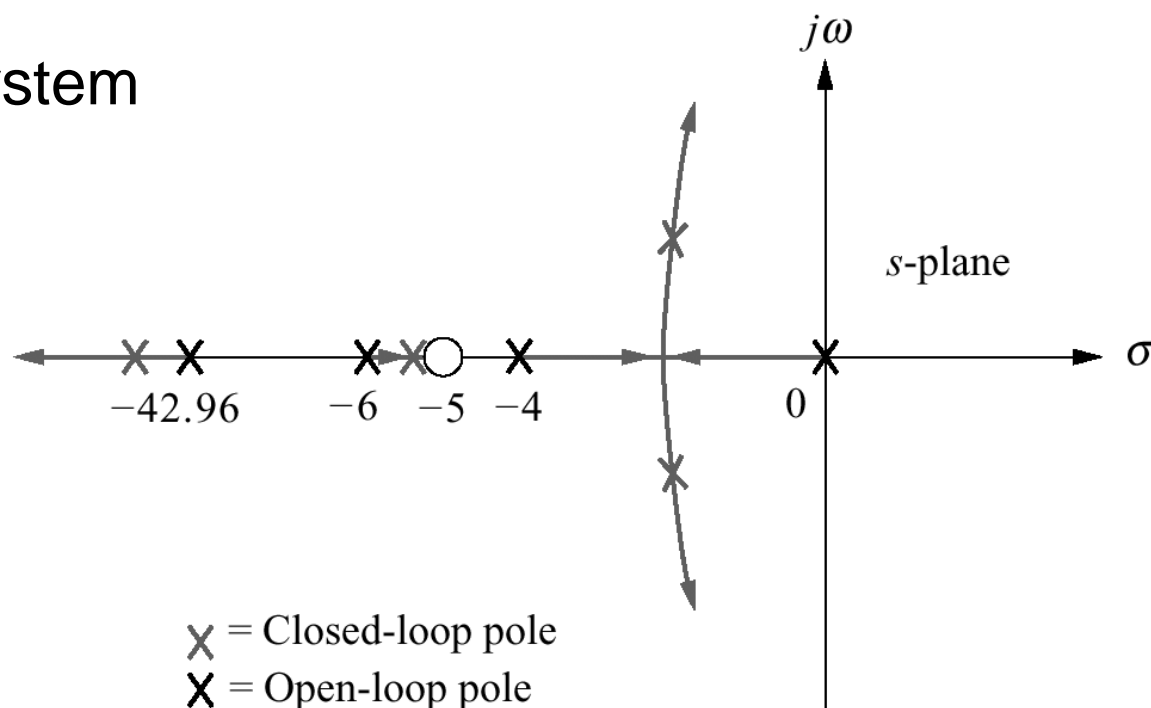
Figure 9.27

s-plane picture
used to calculate
the location of the
compensator pole for
Example 9.4



Note: This figure is not drawn to scale.

Figure 9.28
Compensated system
root locus



Note: This figure is not drawn to scale.

Figure 9.29
Uncompensated system and lead compensation responses for Example 9.4

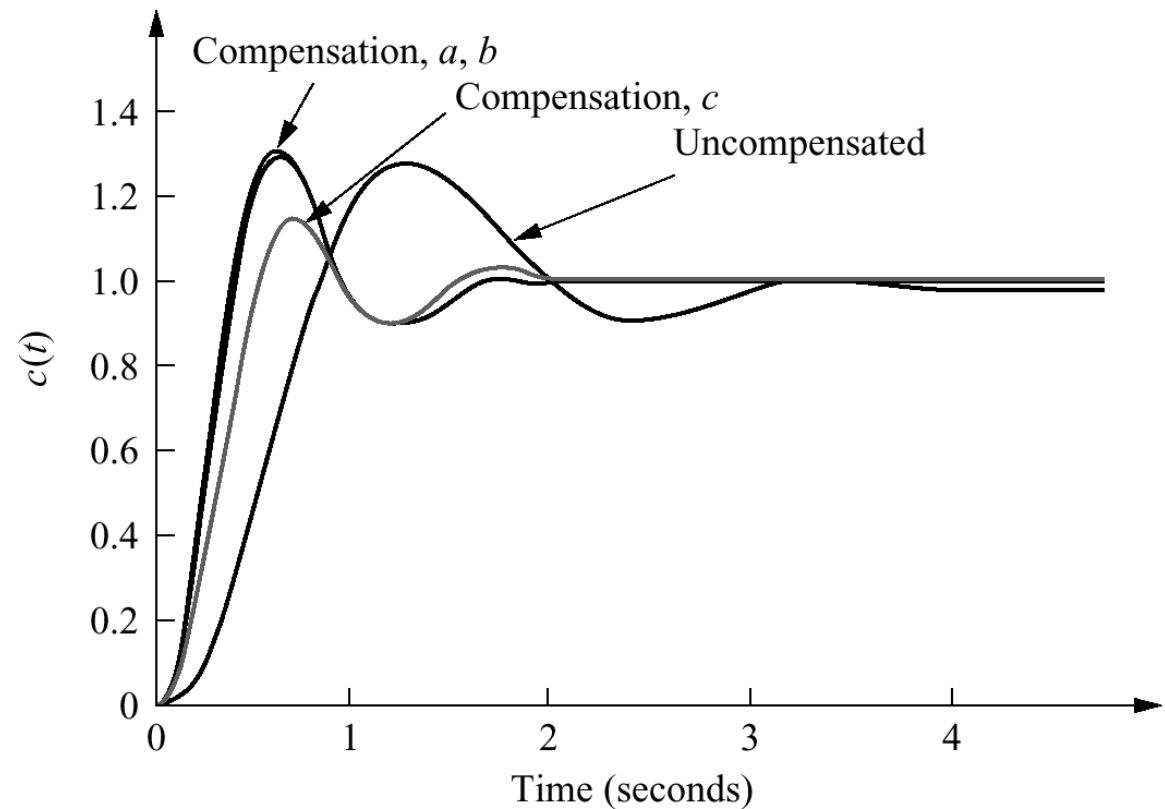


Figure 9.30
PID controller

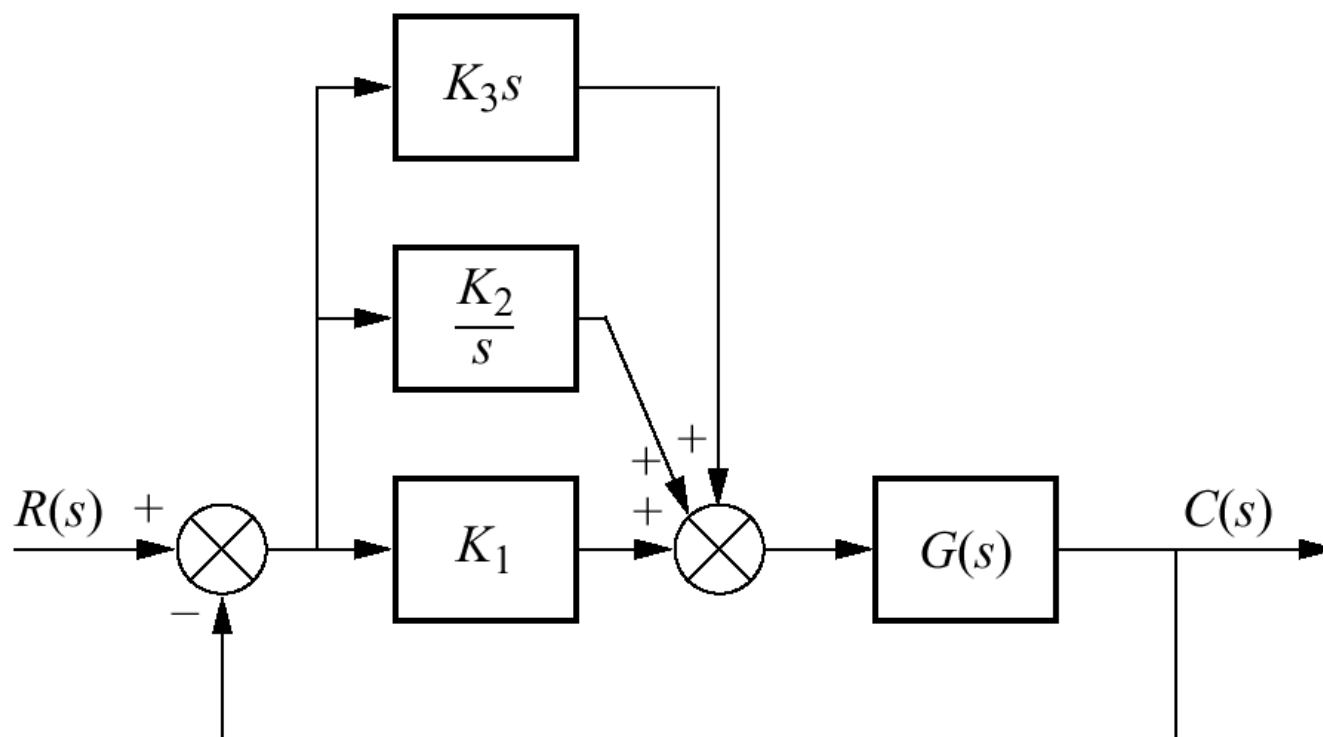


Figure 9.31
Uncompensated
feedback control
system for
Example 9.5

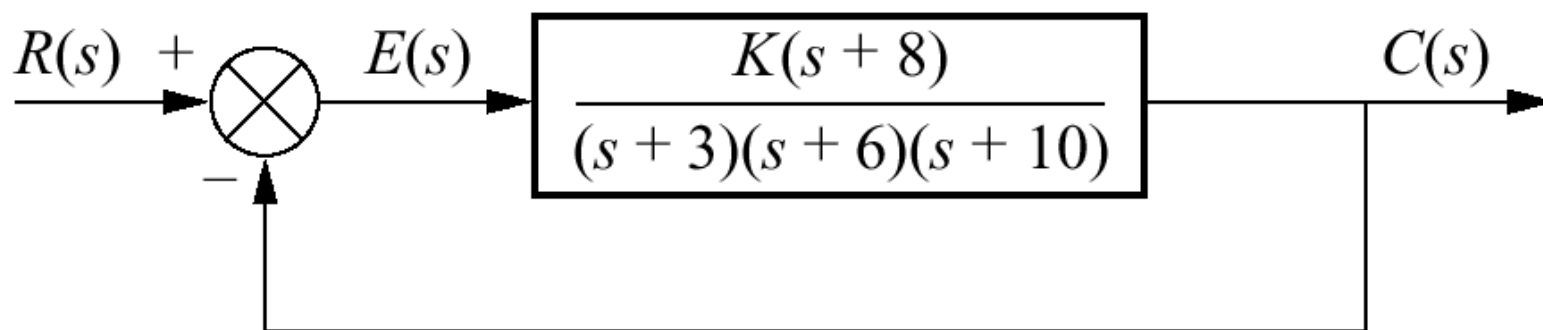


Figure 9.32
Root locus for the
uncompensated
system of
Example 9.5

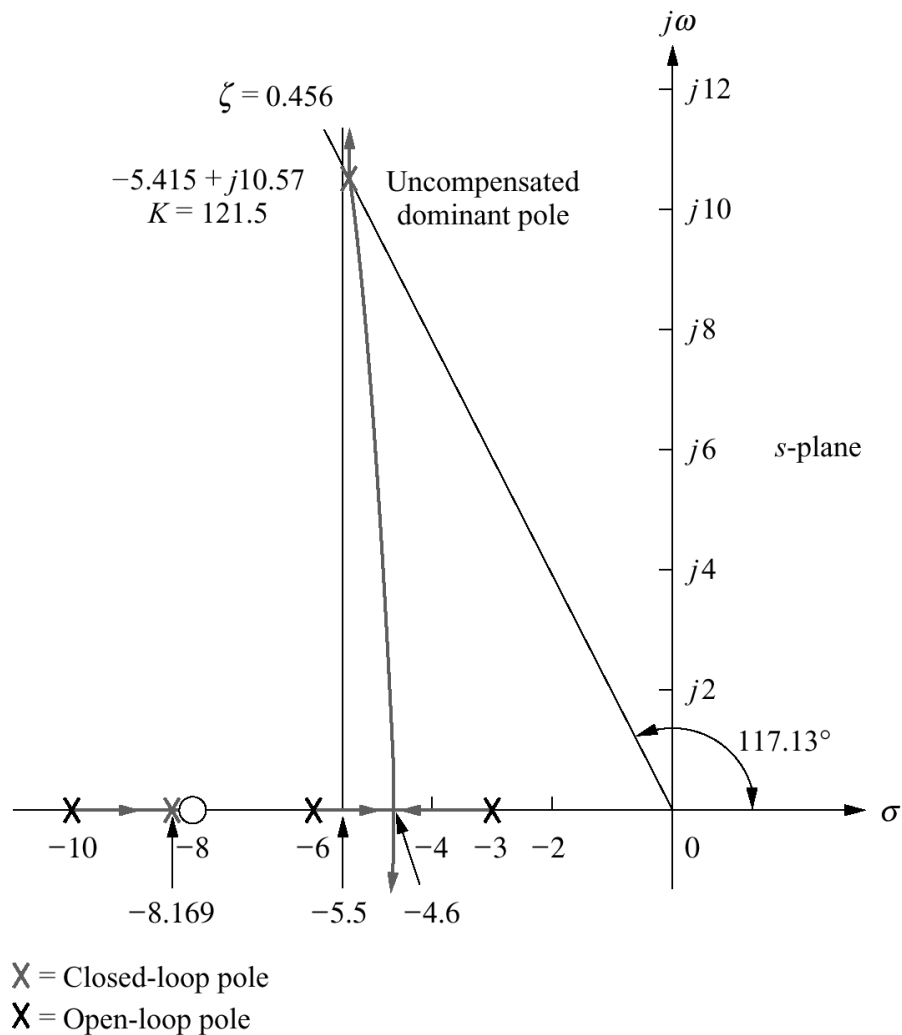
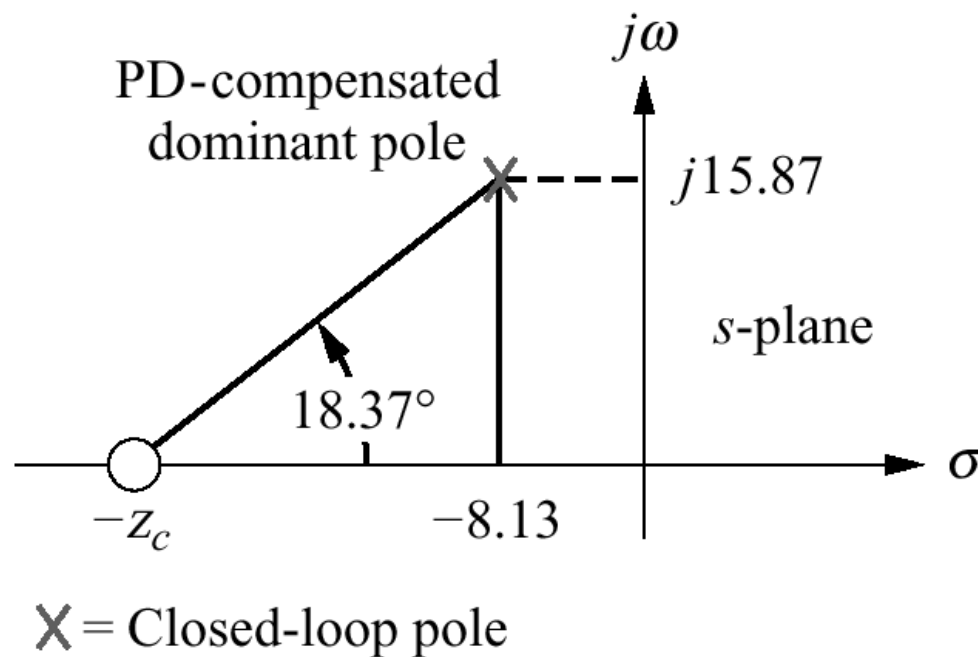
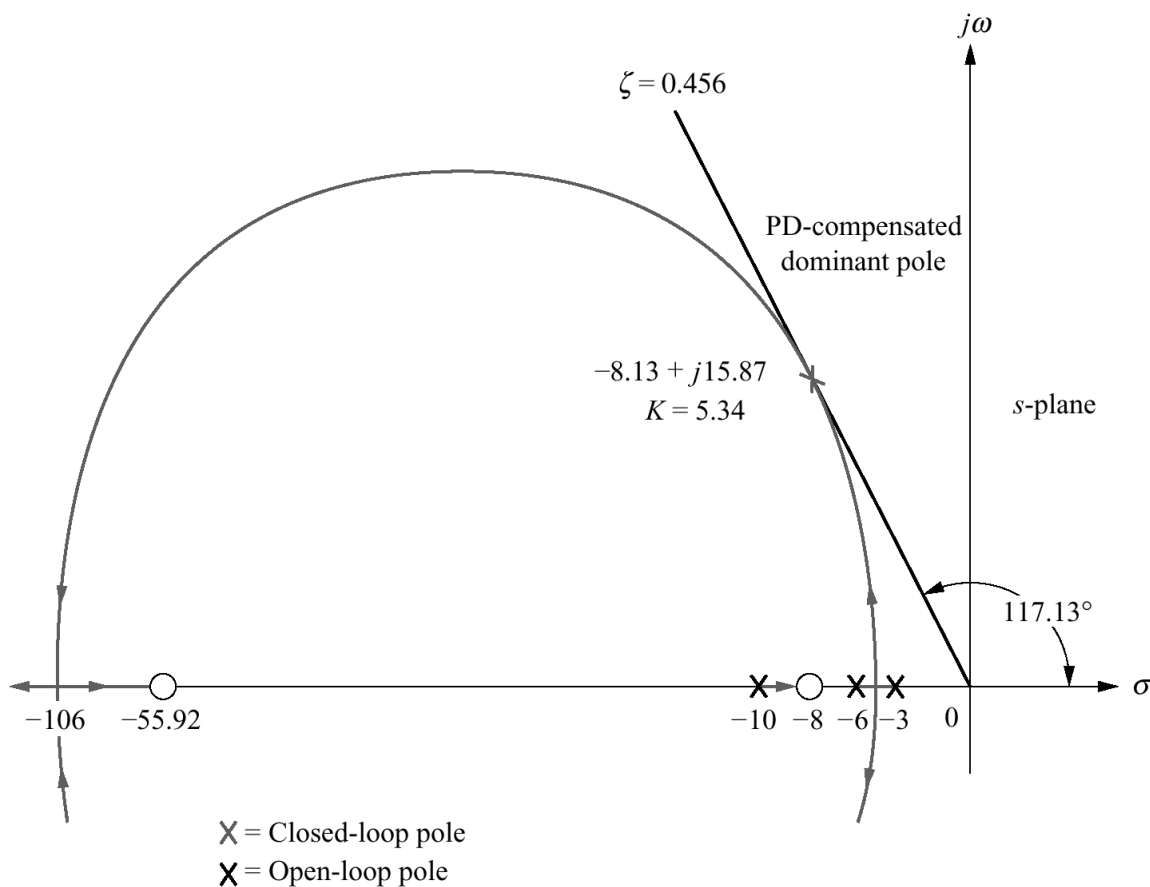


Figure 9.33
Calculating the PD
compensator zero
for Example 9.5



Note: This figure is not drawn to scale.

Figure 9.34
Root locus for
PD-compensated
system of
Example 9.5



Note: This figure is not drawn to scale.

Figure 9.35

Step responses for uncompensated, PD-compensated, and PID-compensated systems of Example 9.5

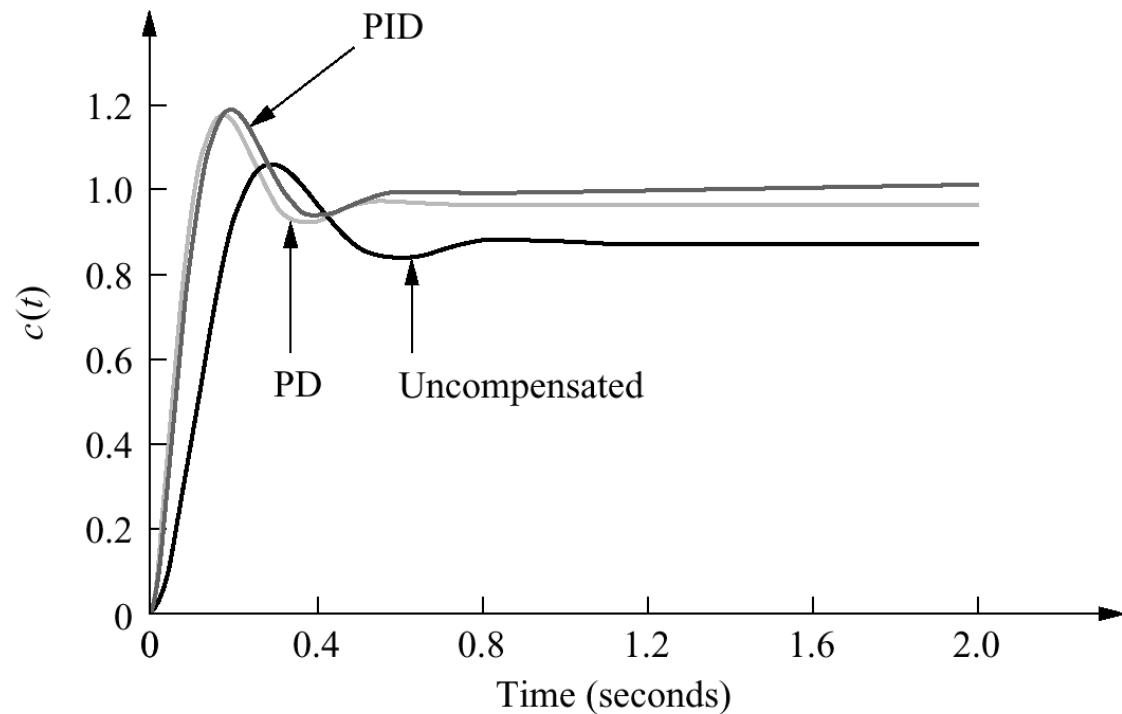
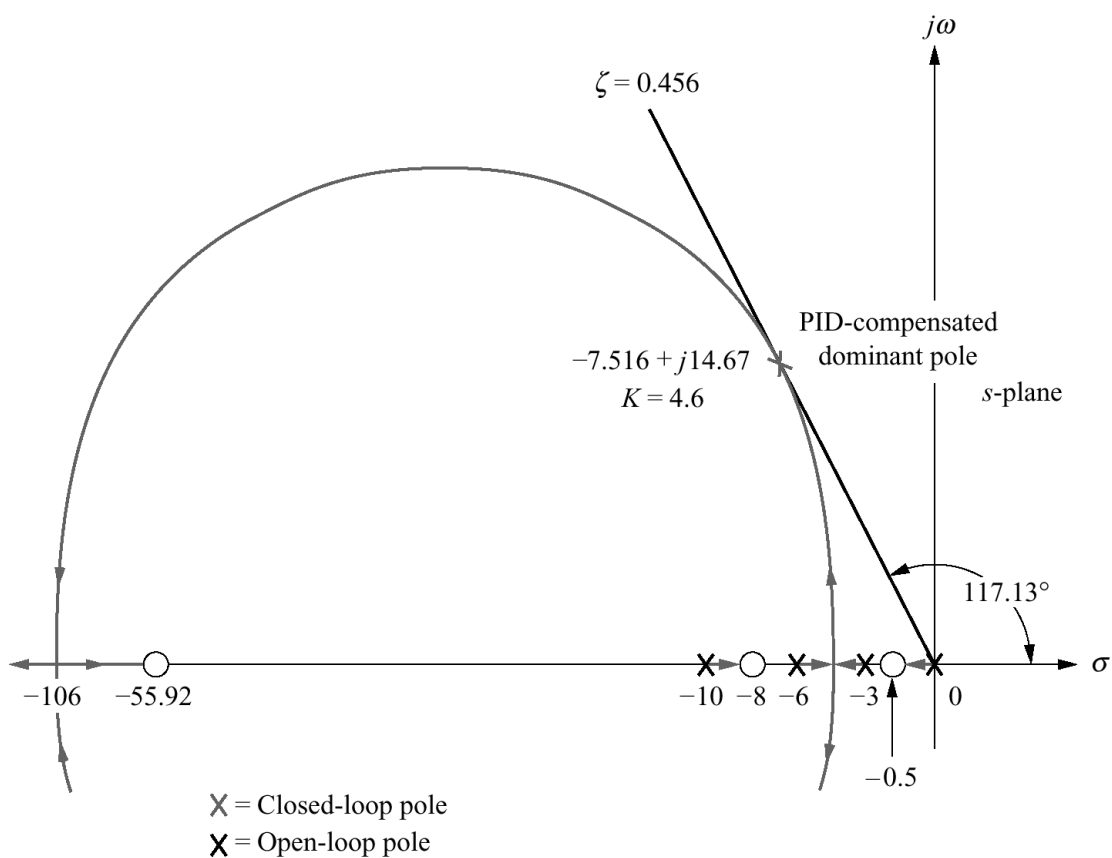


Figure 9.36
Root locus for PID-compensated system
of Example 9.5



Note: This figure is not drawn to scale.

Figure 9.37
Uncompensated
system for
Example 9.6

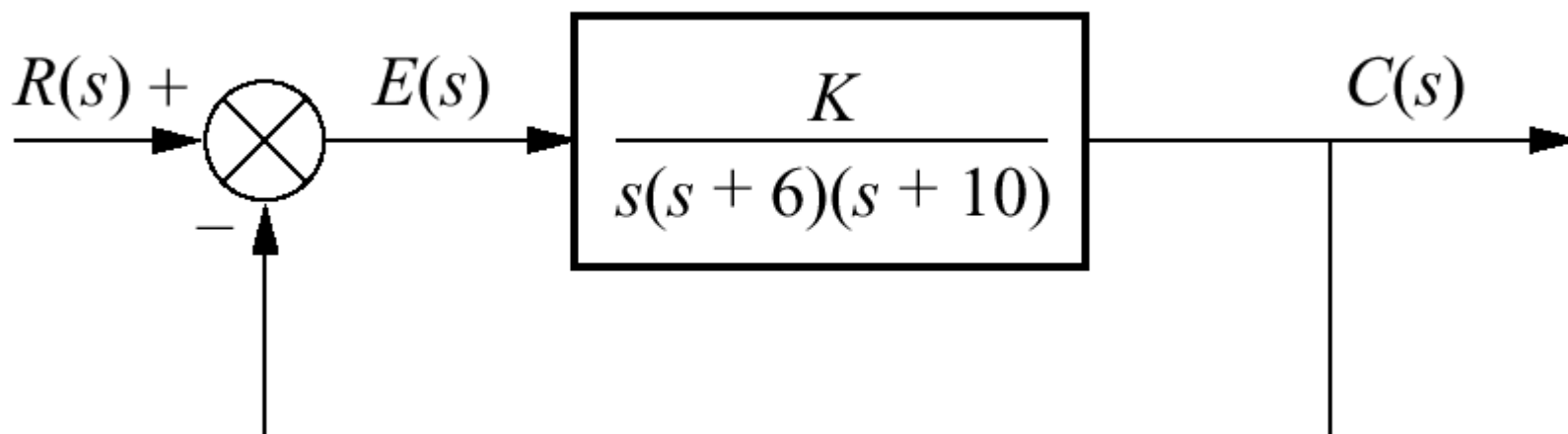


Figure 9.38
Root locus for
uncompensated
system of
Example 9.6

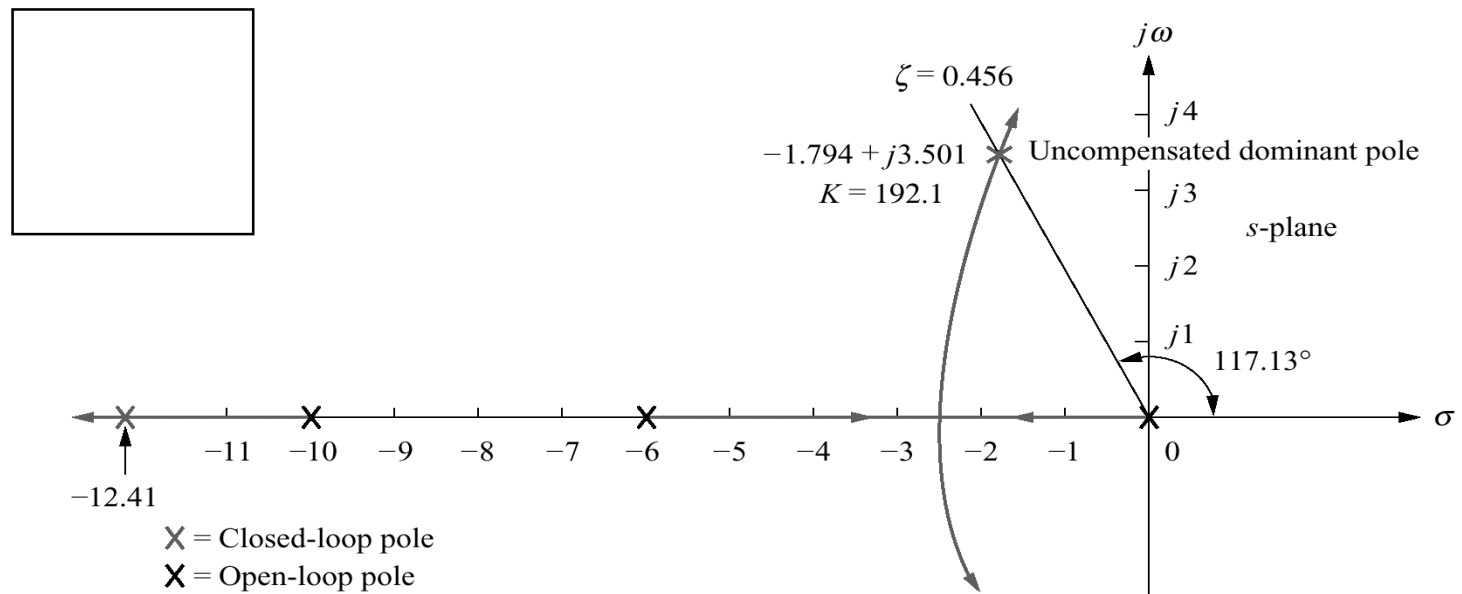


Figure 9.39
Evaluating the
compensator pole for
Example 9.6

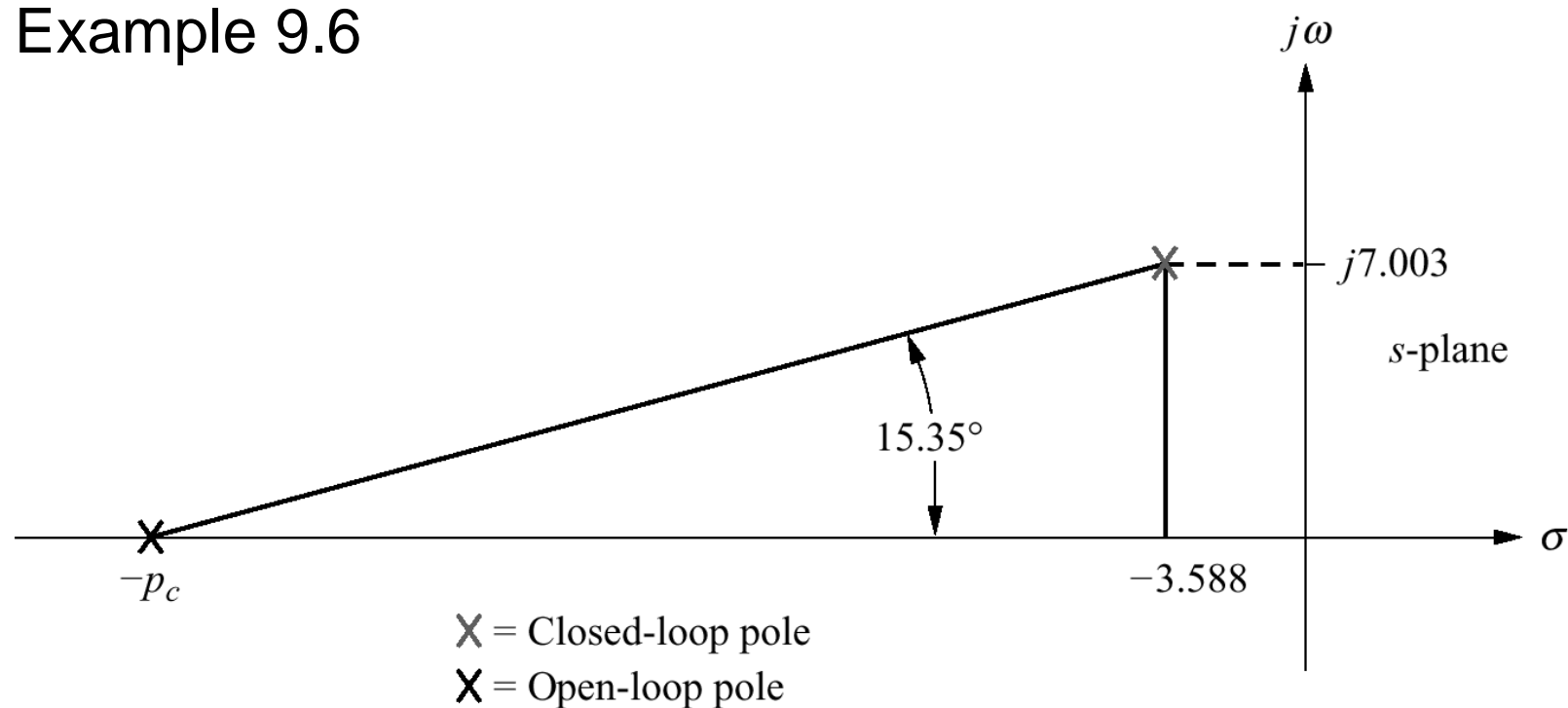


Figure 9.40
Root locus for
lead-compensated
system of
Example 9.6

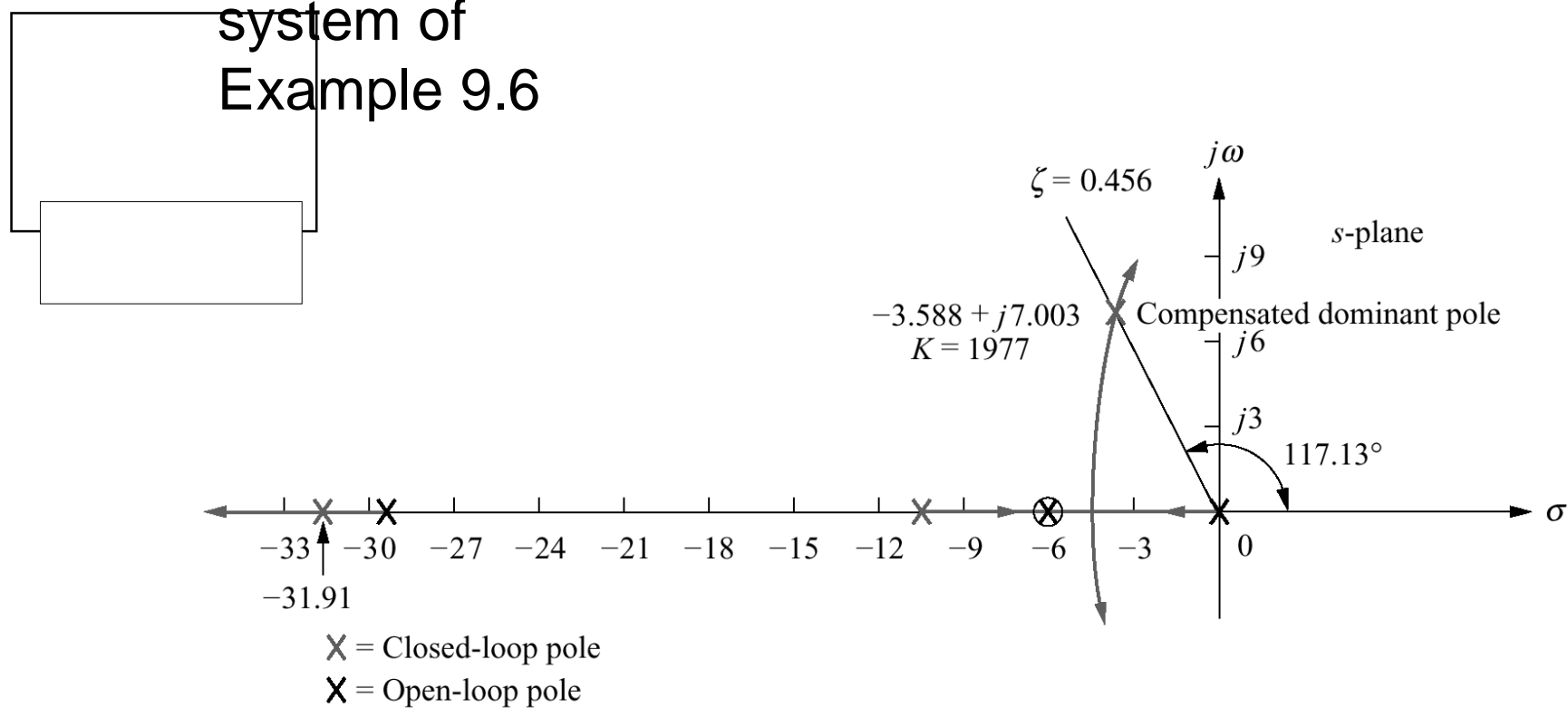
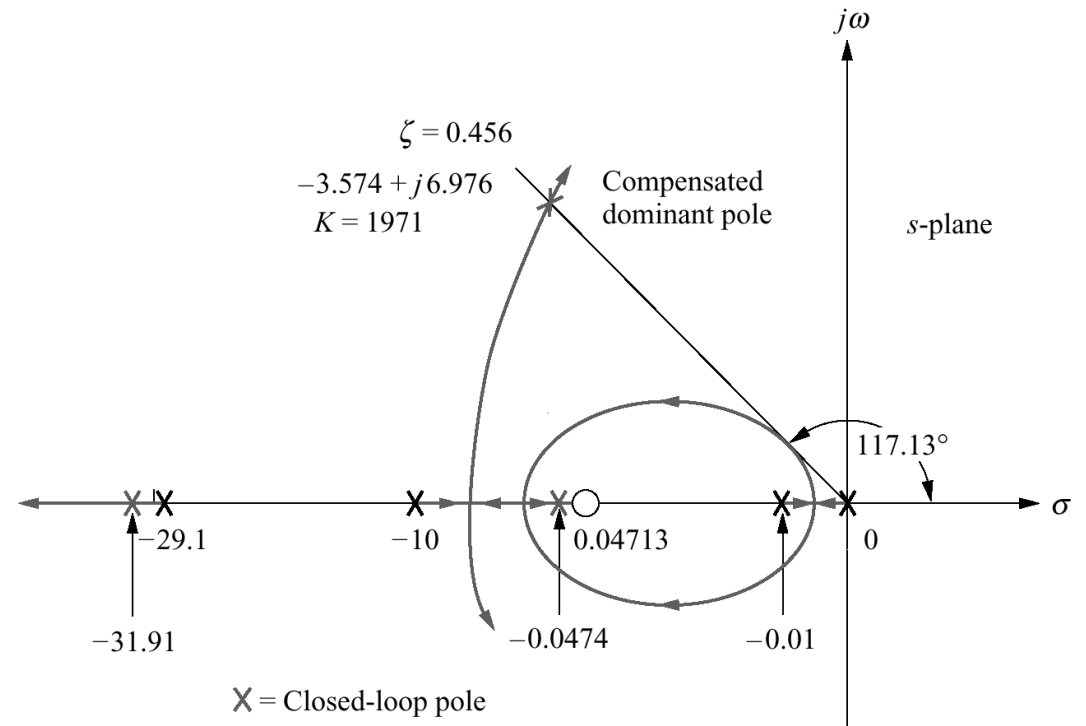


Figure 9.41
Root locus for lag-lead-compensated system
of Example 9.6



Note: This figure is not drawn to scale.

Figure 9.42
Improvement in step
response for
lag- lead-
compensated
system of
Example 9.6

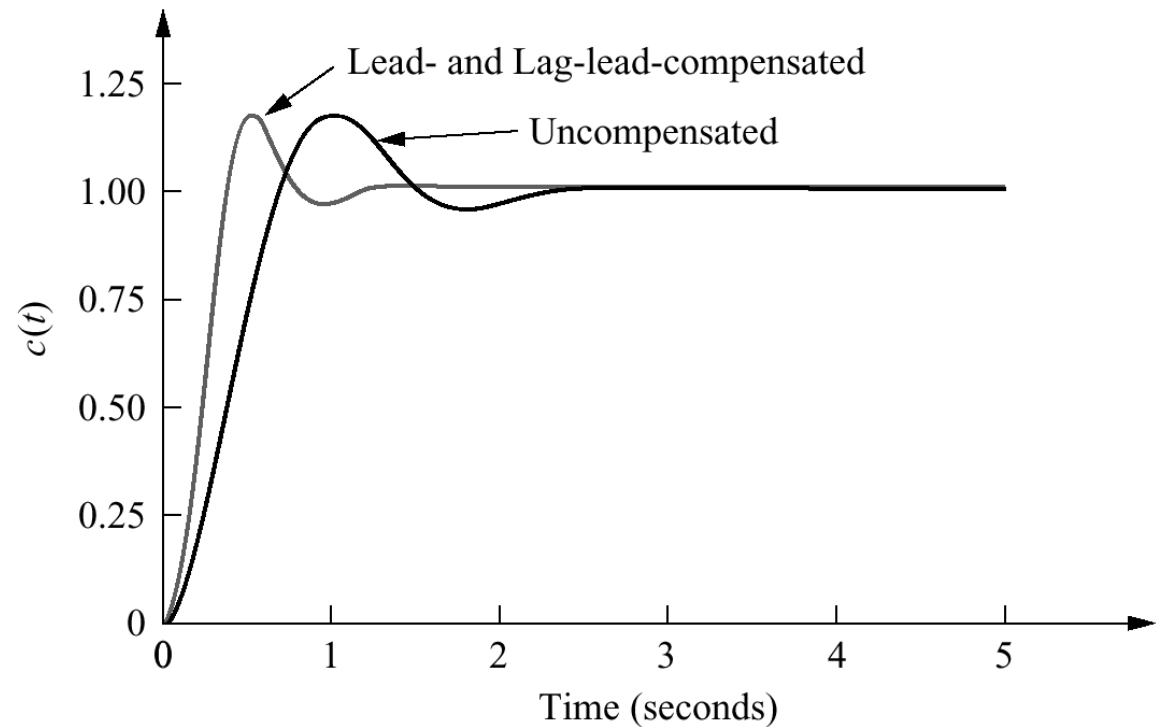


Figure 9.43

Improvement in
ramp response error
for the system of
Example 9.6:

a. lead-compensated;

b. lag-lead-
compensated

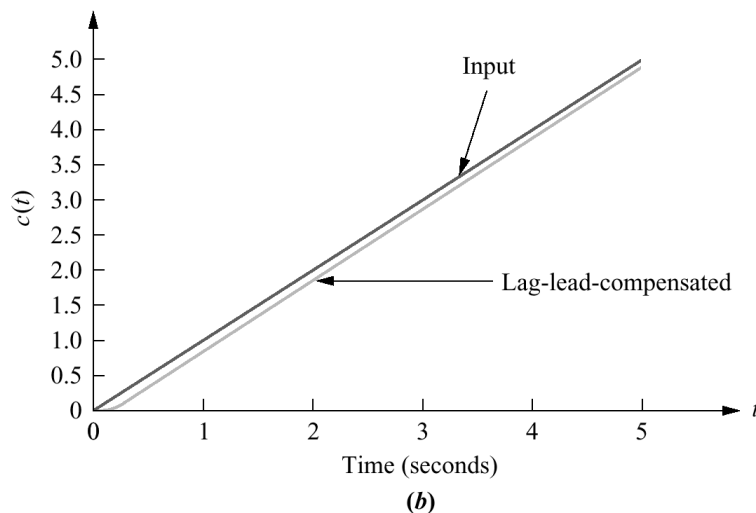
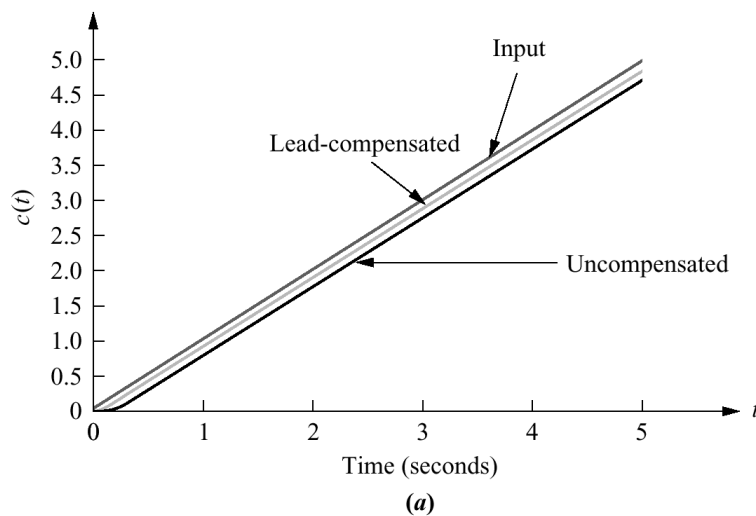


Figure 9.44

- a.** Root locus before cascading notch filter;
b. typical closed-loop step response before cascading notch filter;
(figure continues)

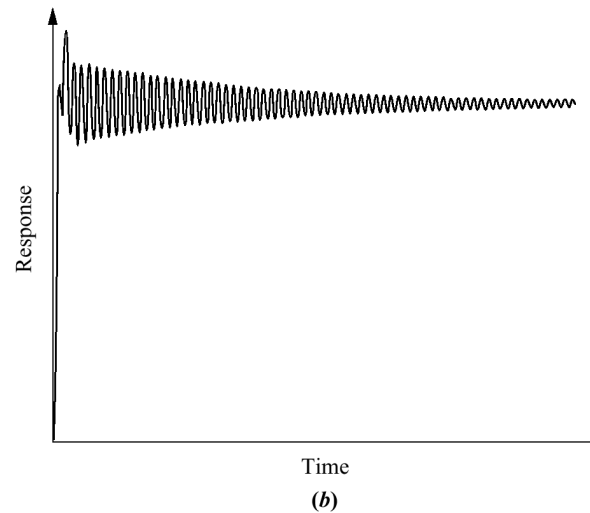
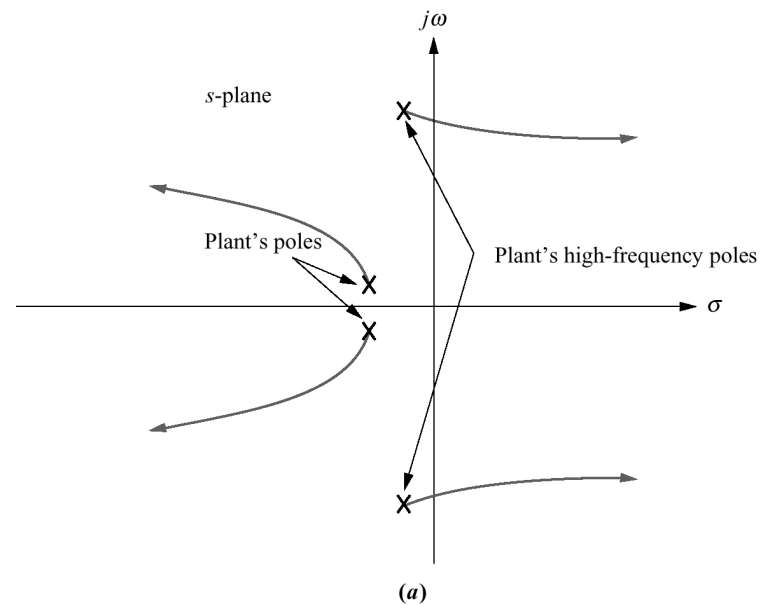


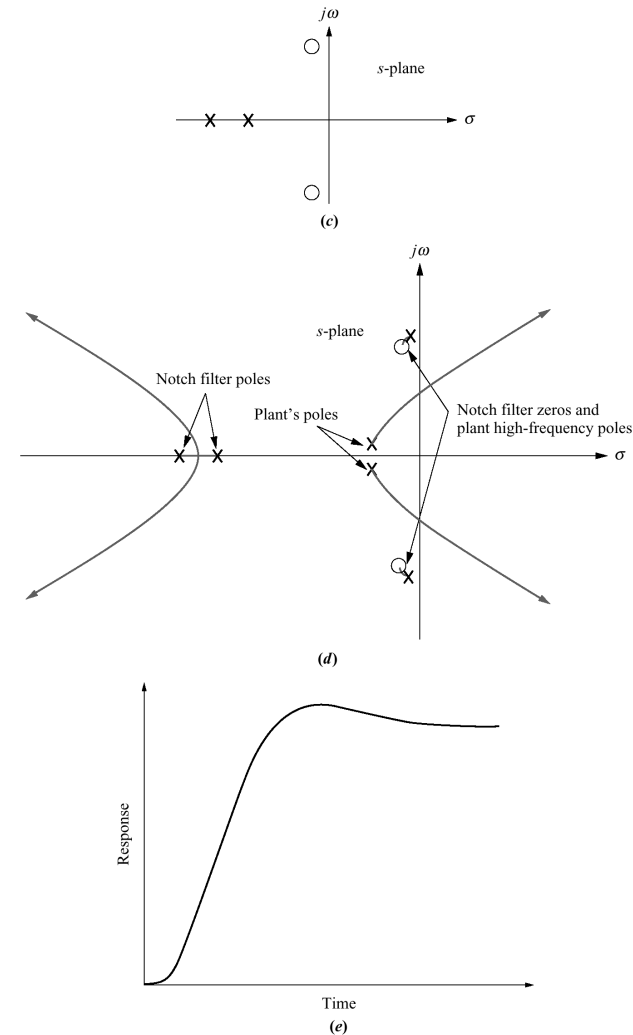
Figure 9.44*(continued)***c.** pole-zero plot
of a notch filter;**d.** root locus after
cascading notch
filter;**e.** closed-loop step
response after
cascading notch
filter.

Figure 9.45
Generic control
system with feedback
compensation

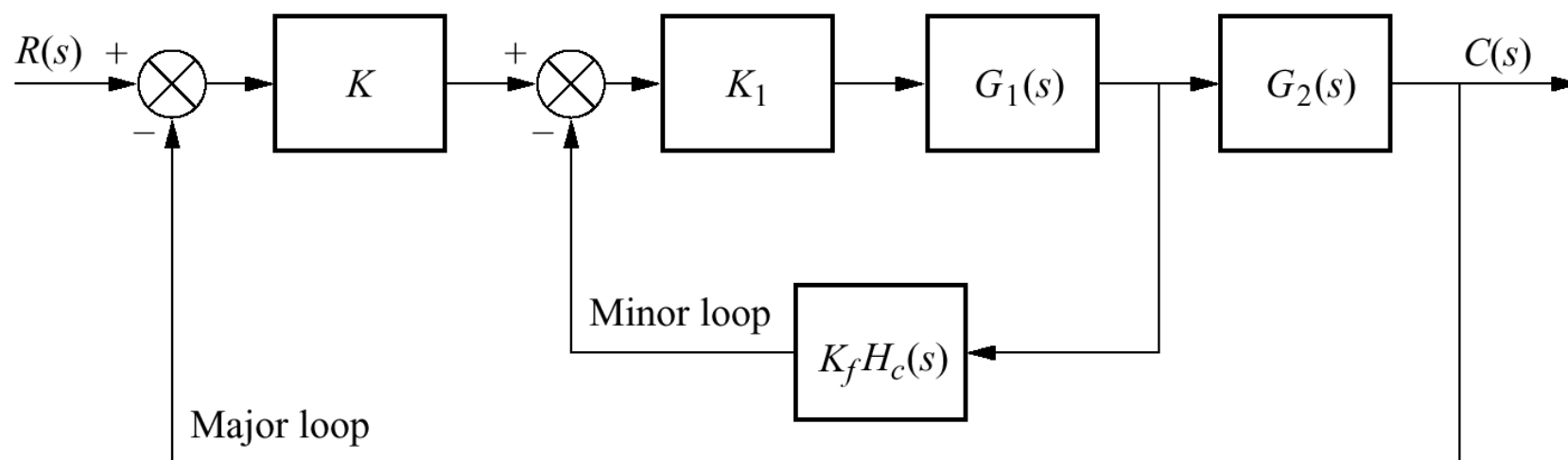


Figure 9.46

A position control system that uses a tachometer as a differentiator in the feedback path. Can you see the similarity between this system and the schematic on the front end papers?

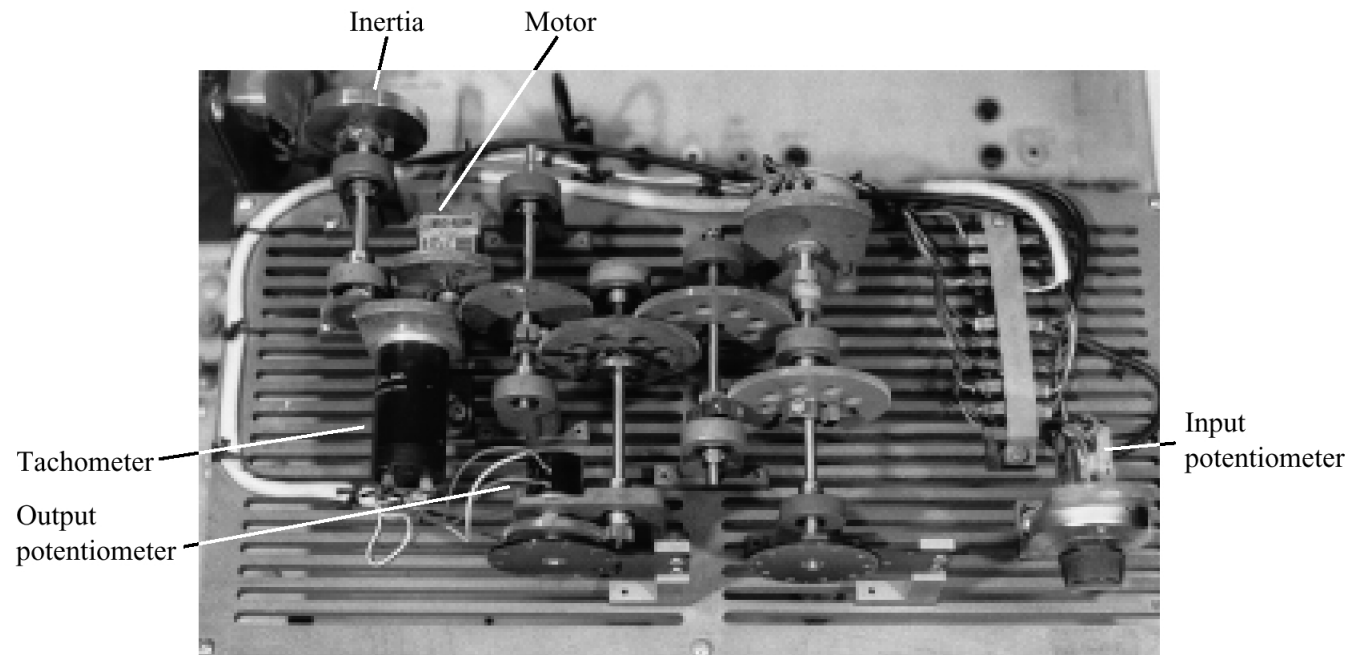


Figure 9.47

- a.** Transfer function of a tachometer;
b. tachometer feedback compensation

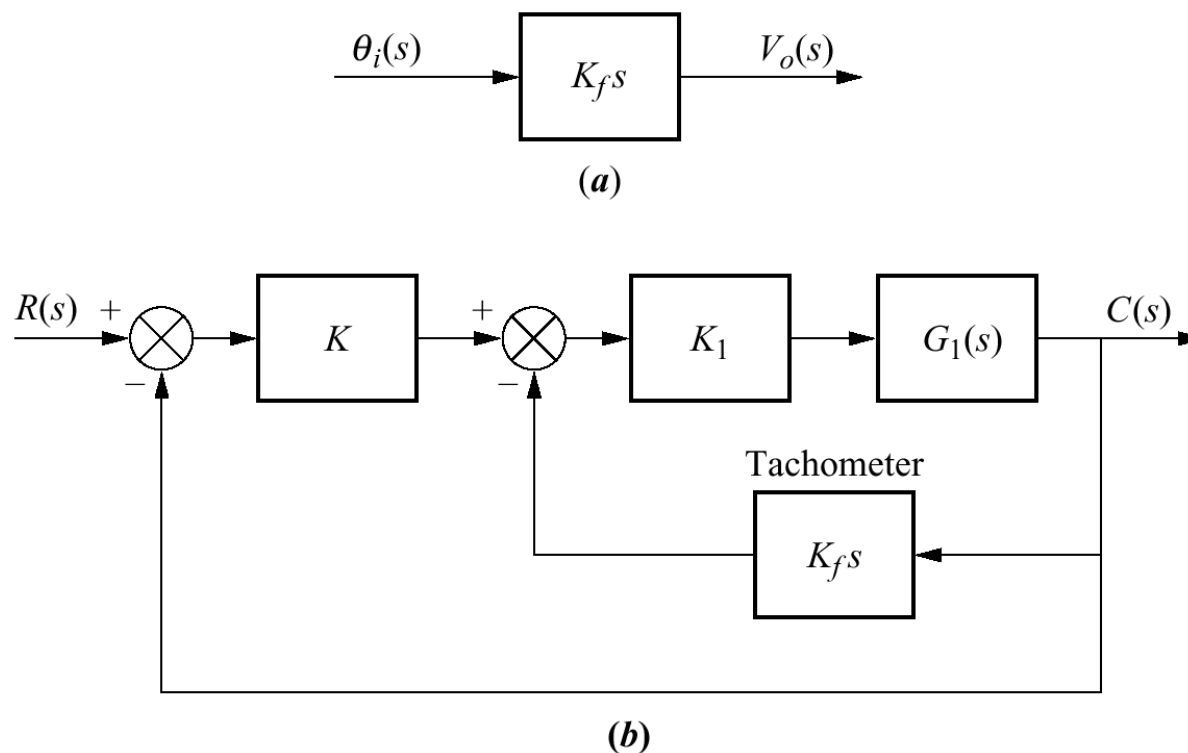


Figure 9.48
Equivalent
block diagram
of Figure 9.45

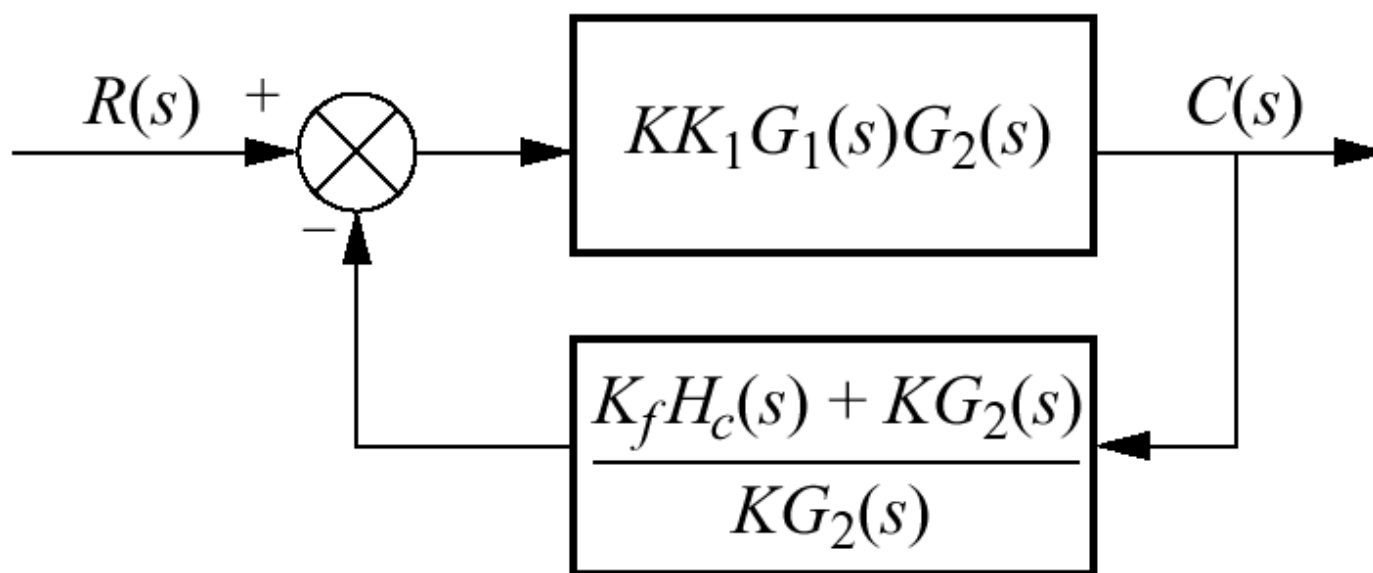


Figure 9.49

a. System for Example 9.7;
b. system with rate feedback compensation;
c. equivalent compensated system;
d. equivalent compensated system, showing unity feedback

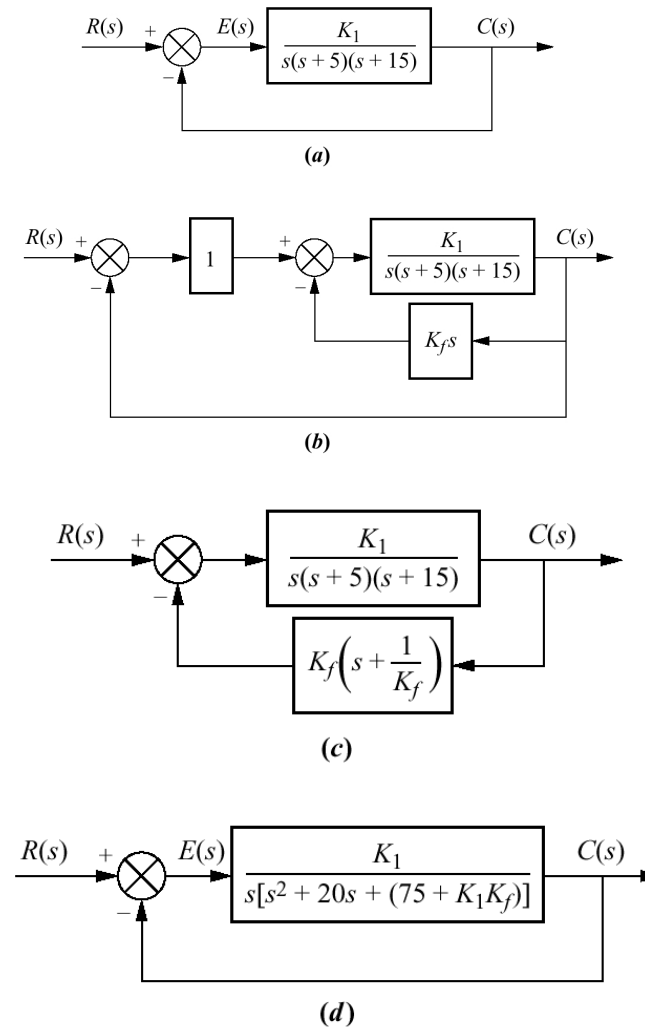


Figure 9.50
Root locus for
uncompensated
system of
Example 9.7

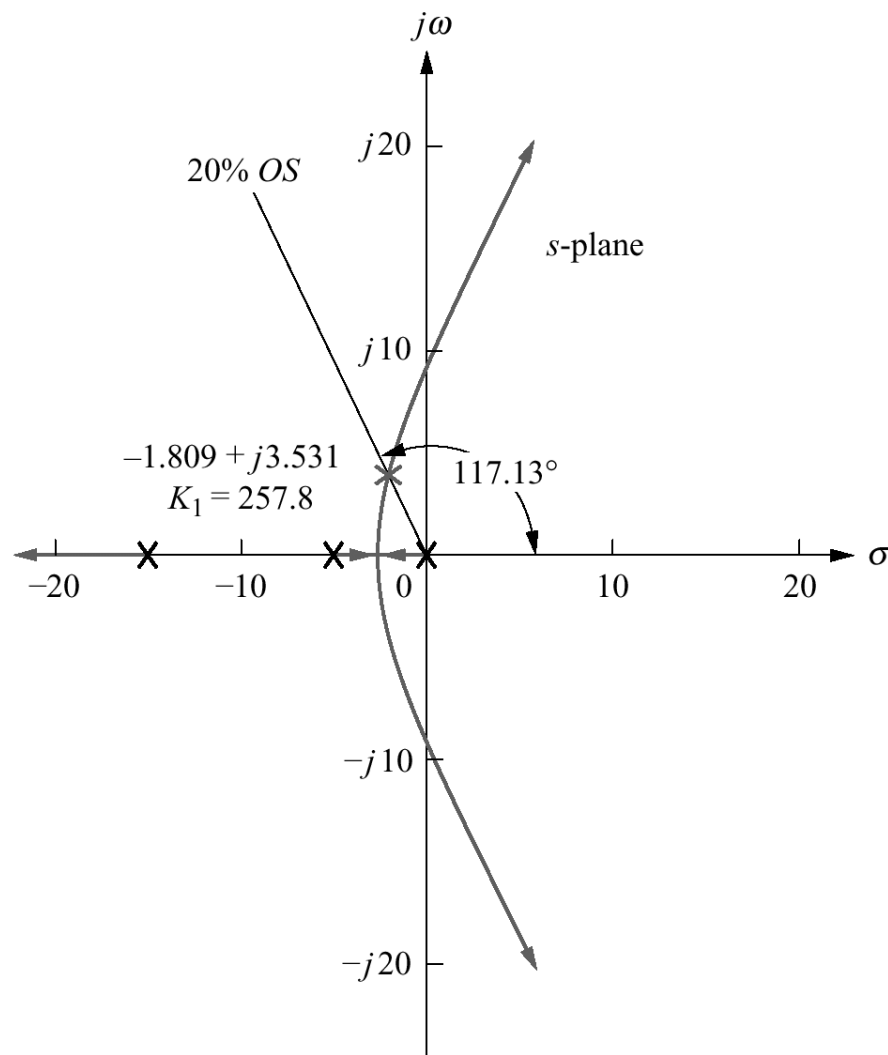


Figure 9.51
Step response for
uncompensated
system of
Example 9.7

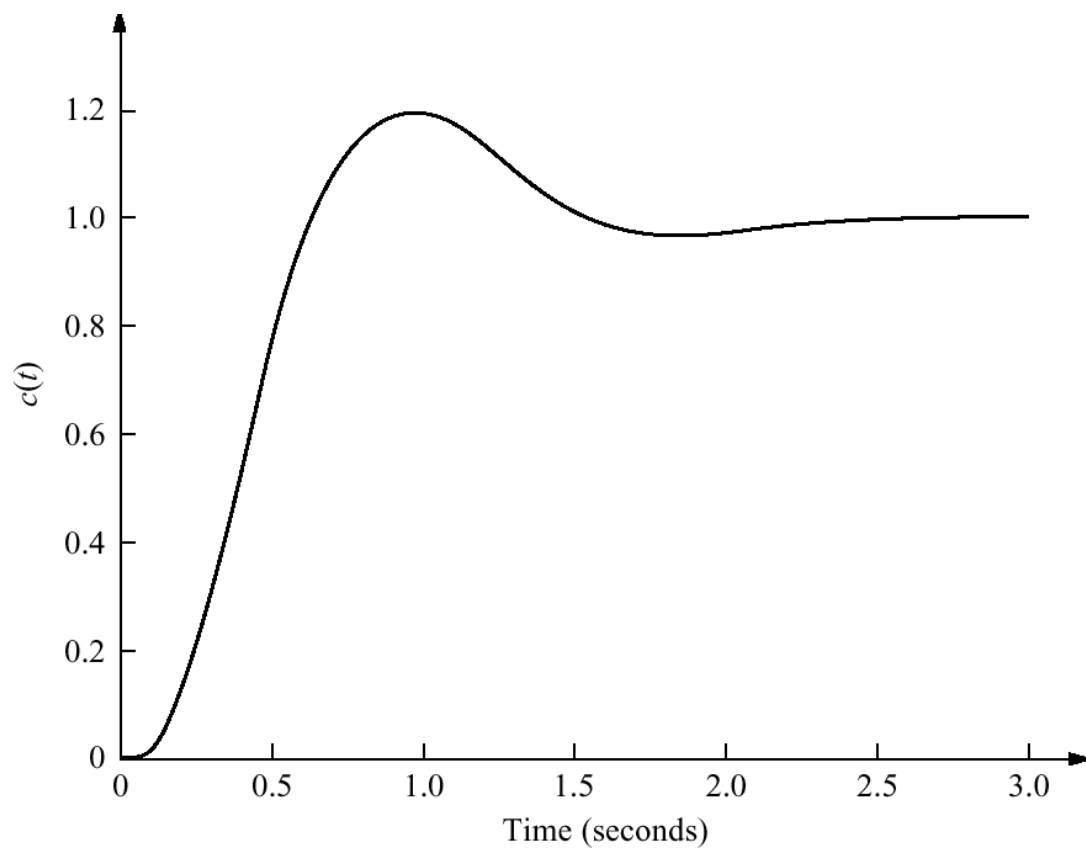


Figure 9.52
Finding the
compensator
zero in
Example 9.7

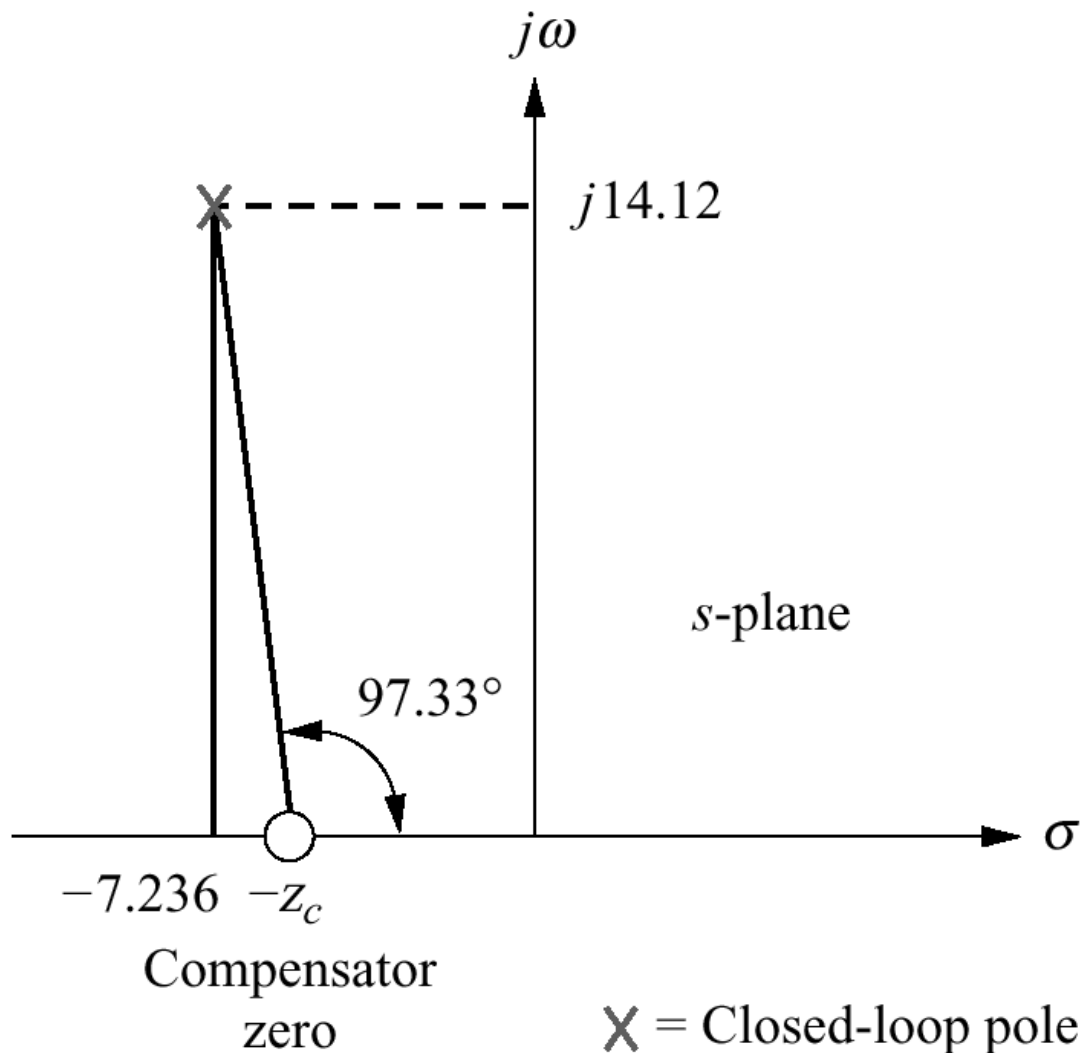


Figure 9.53
Root locus for the
compensated system
of Example 9.7

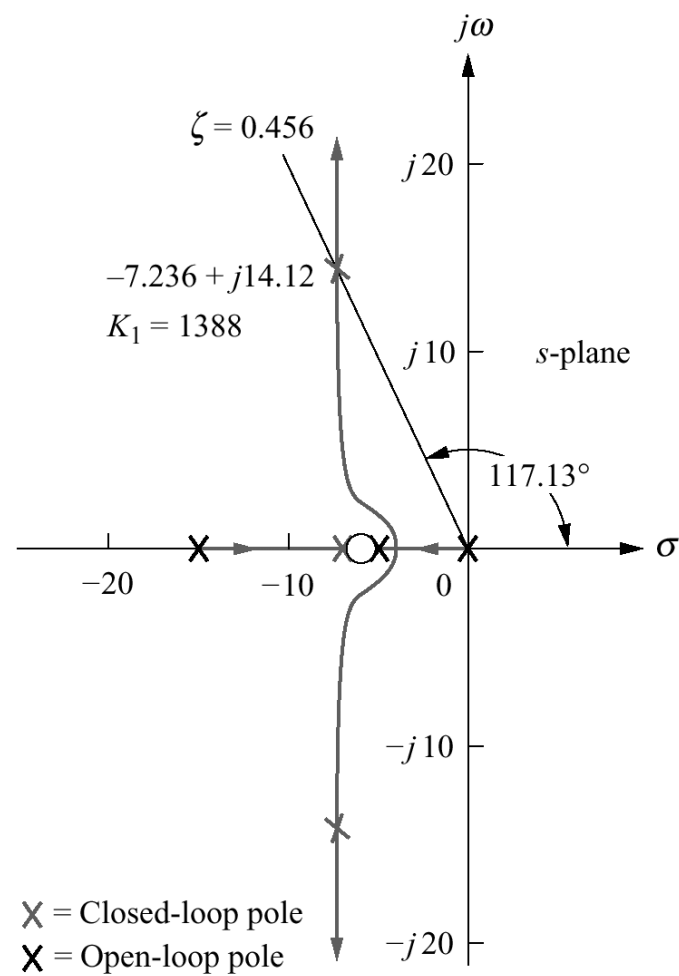


Figure 9.54

Step response for the compensated system of Example 9.7

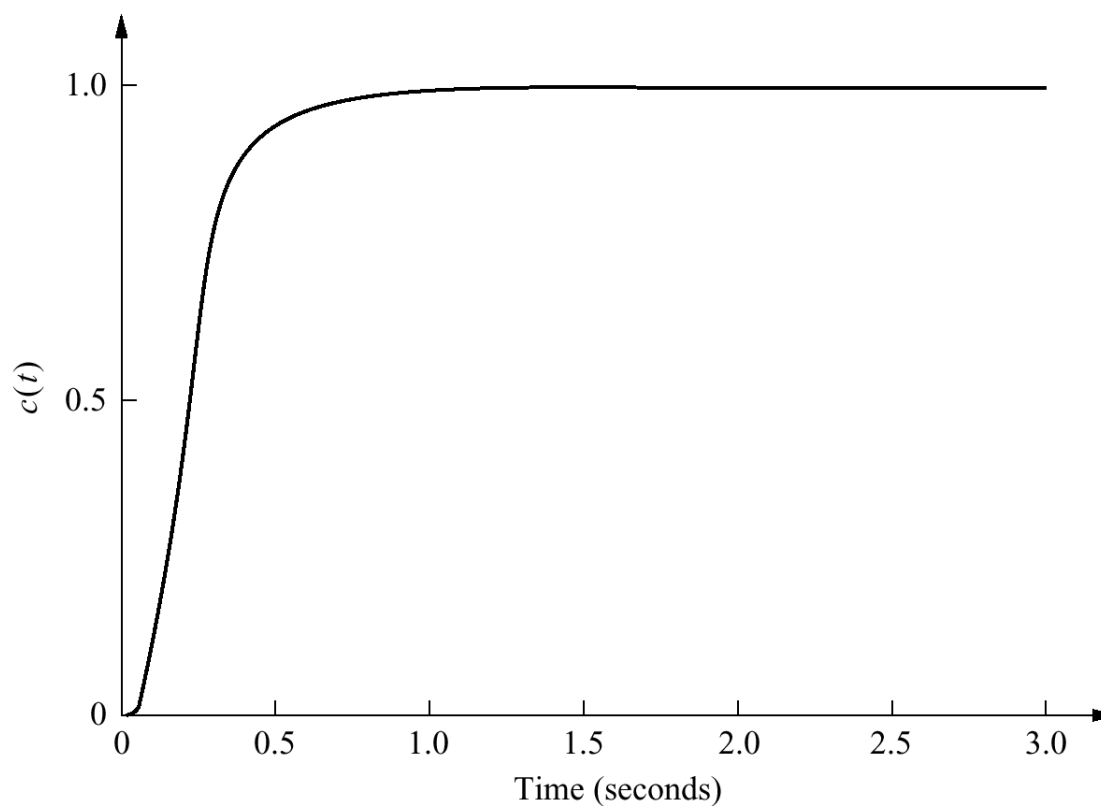


Figure 9.55

a. Uncompensated system and
b. feedback-compensated system
for Example 9.8

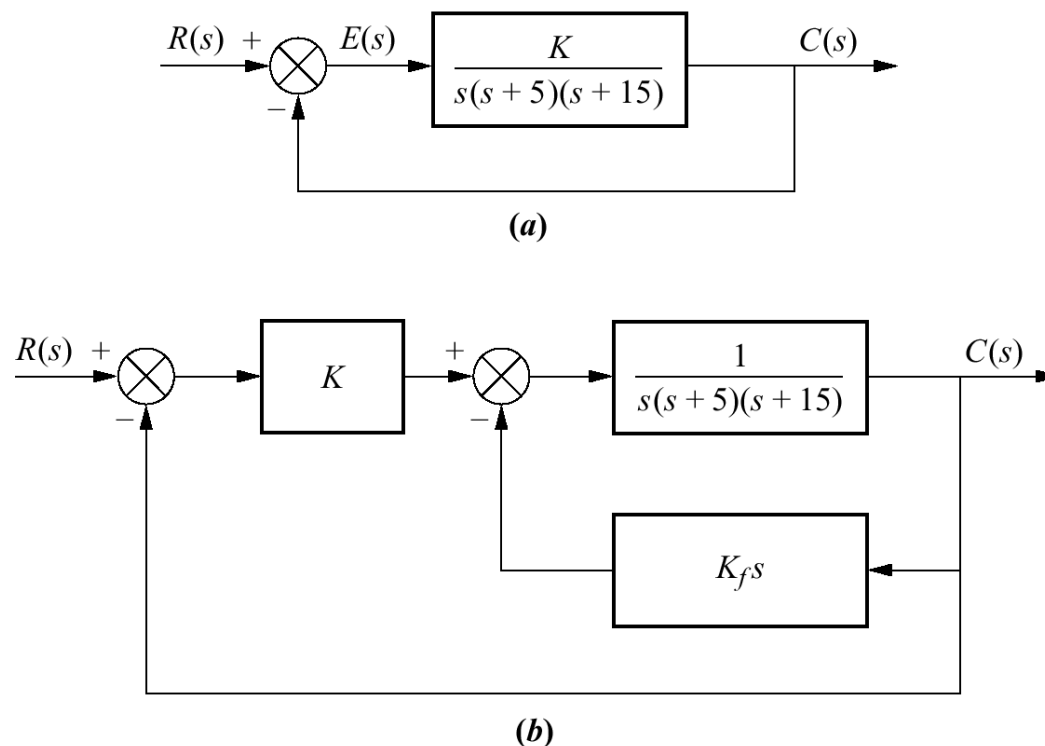


Figure 9.56
Root locus for minor
loop of Example 9.8

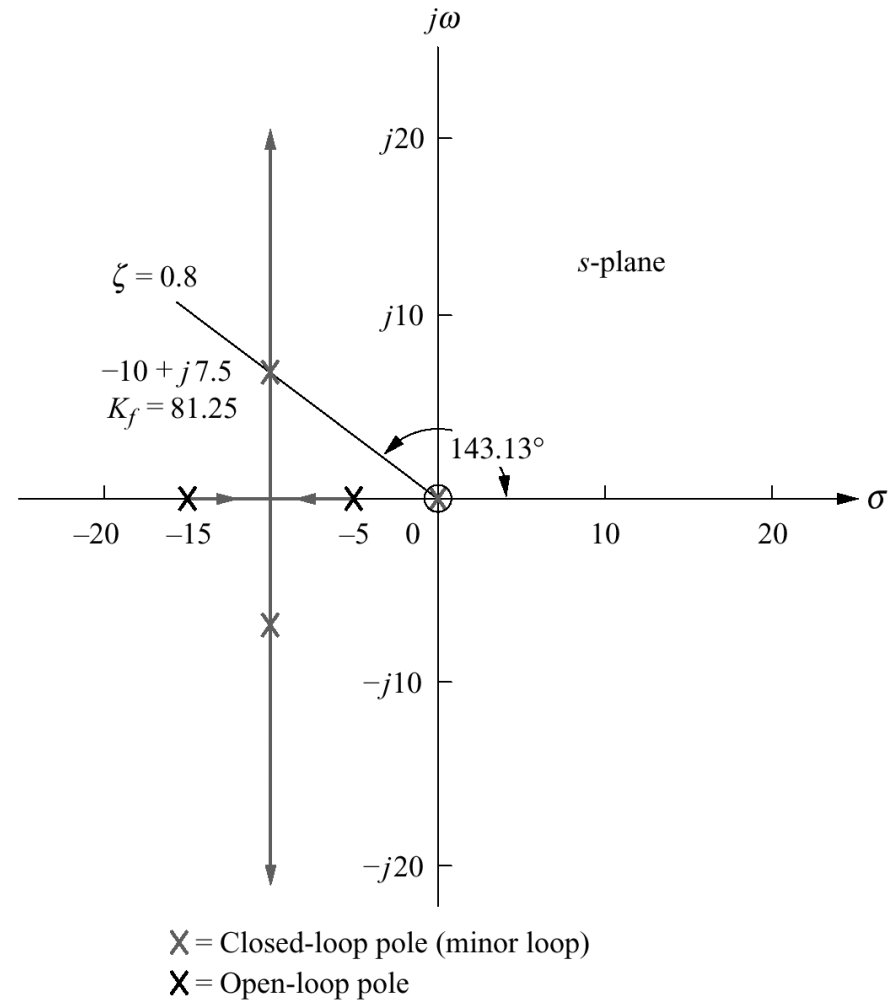


Figure 9.57
Root locus for
closed-loop
system of
Example 9.8

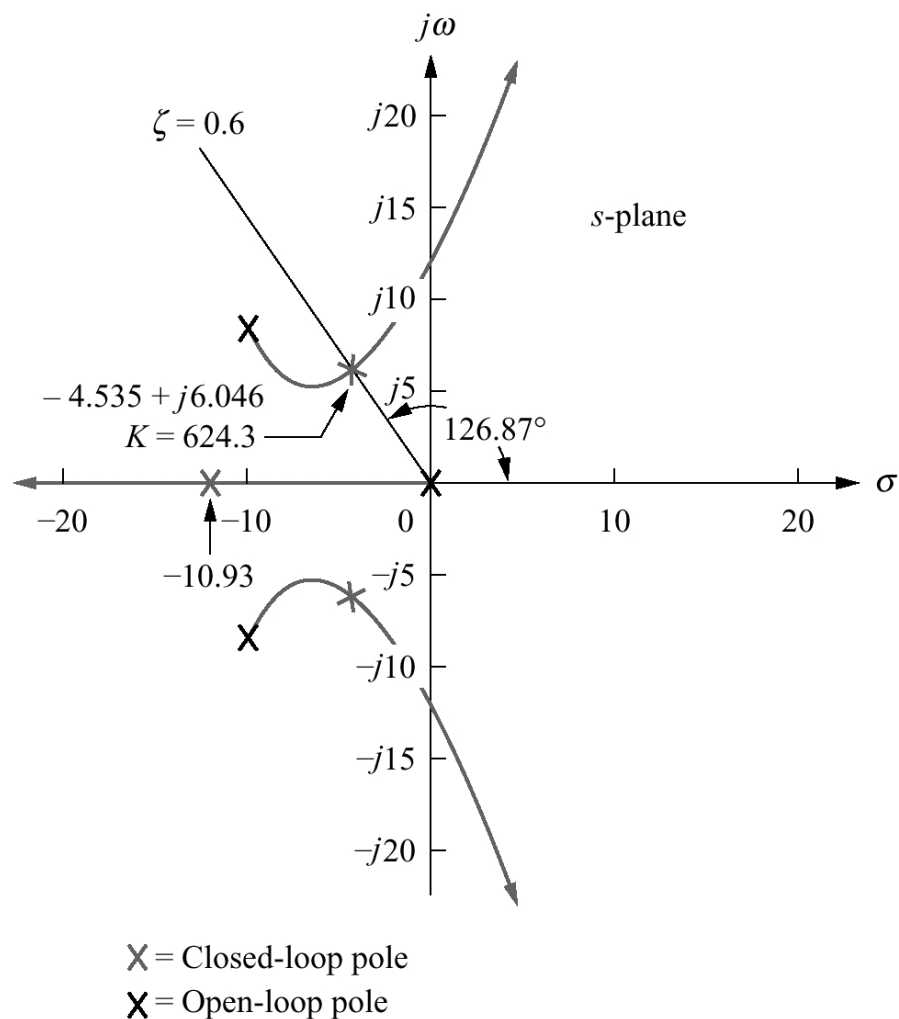


Figure 9.58
Step response
simulation for
Example 9.8

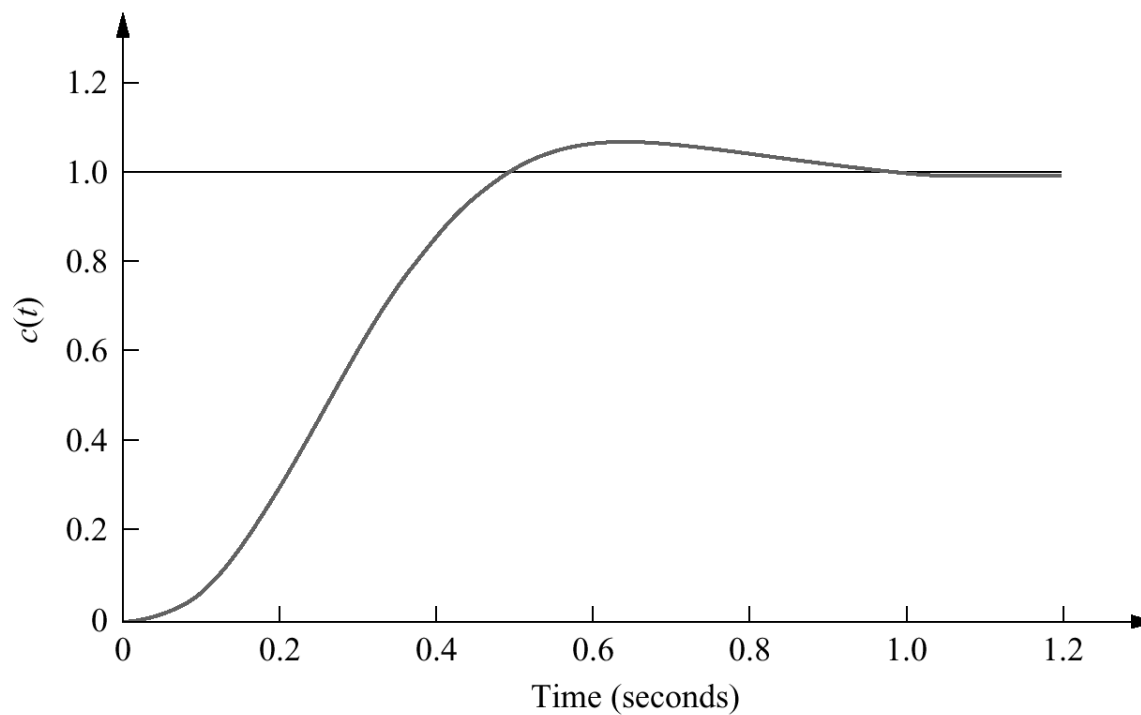


Figure 9.59
System for
Skill-Assessment
Exercise 9.4

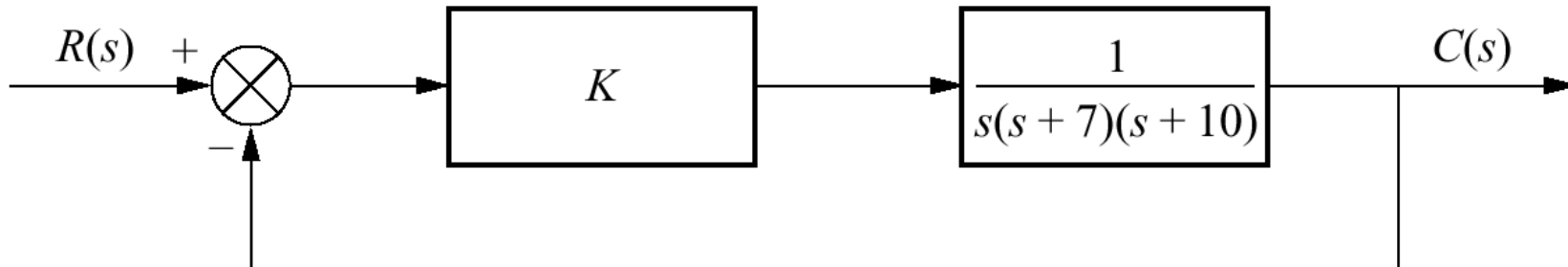


Figure 9.60

Operational amplifier
configured for transfer
function realization

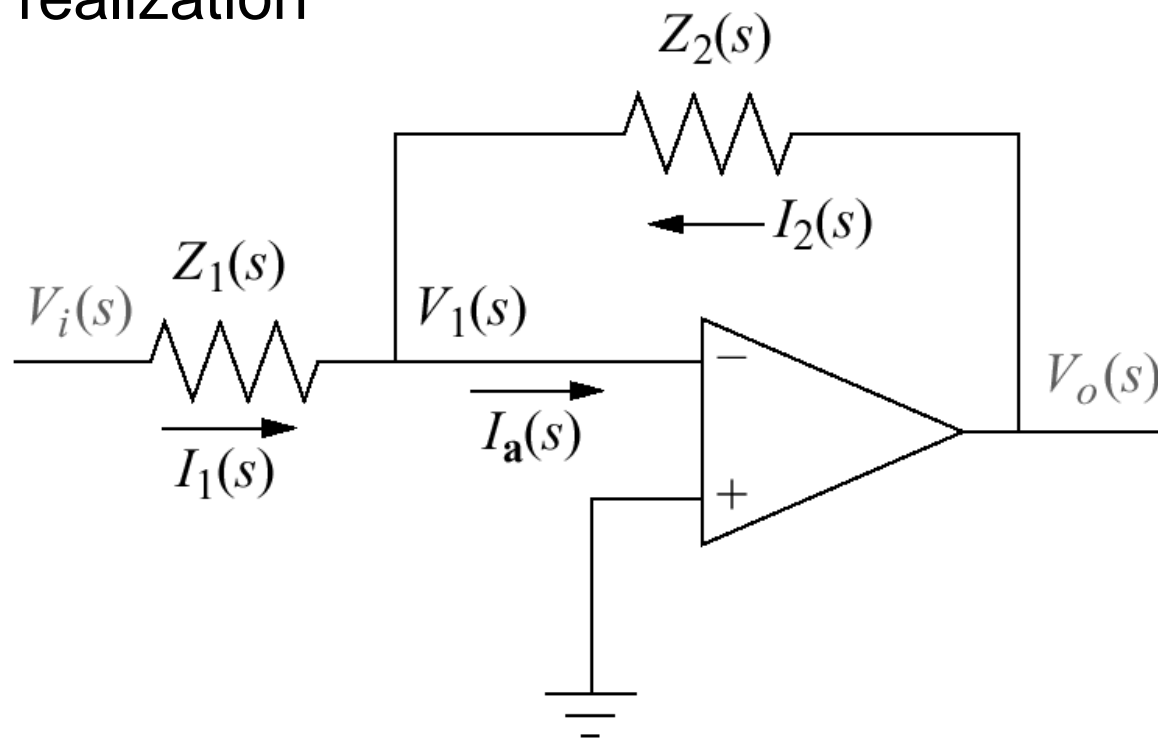


Figure 9.61
Lag-lead compensator
implemented with
operational amplifiers

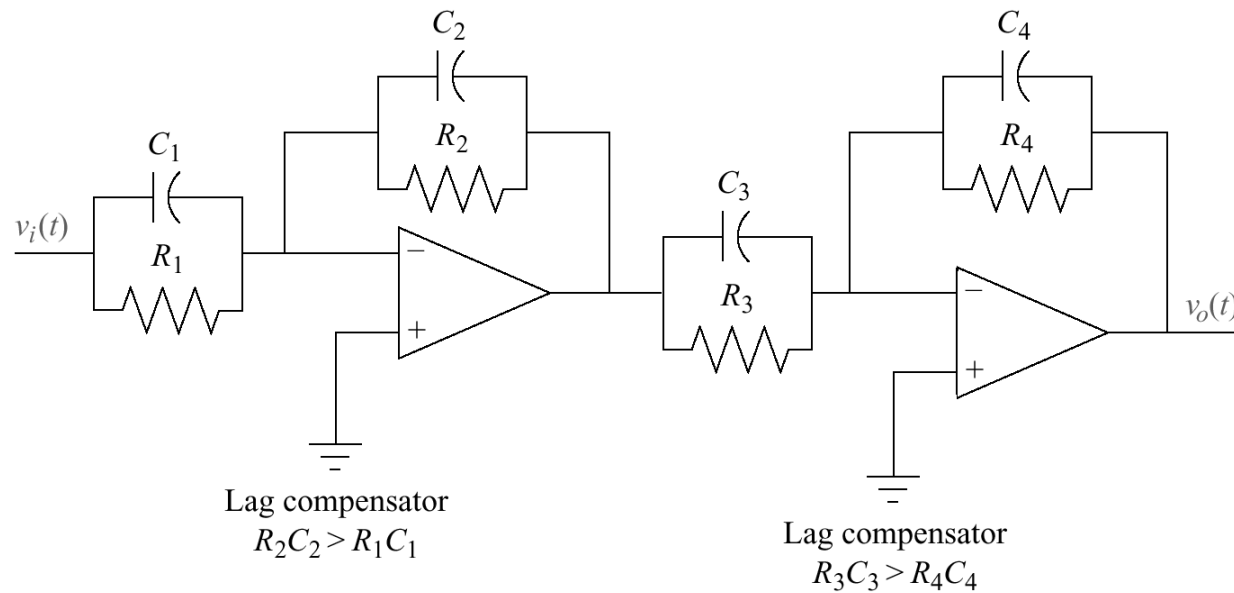


Figure 9.62
PID controller

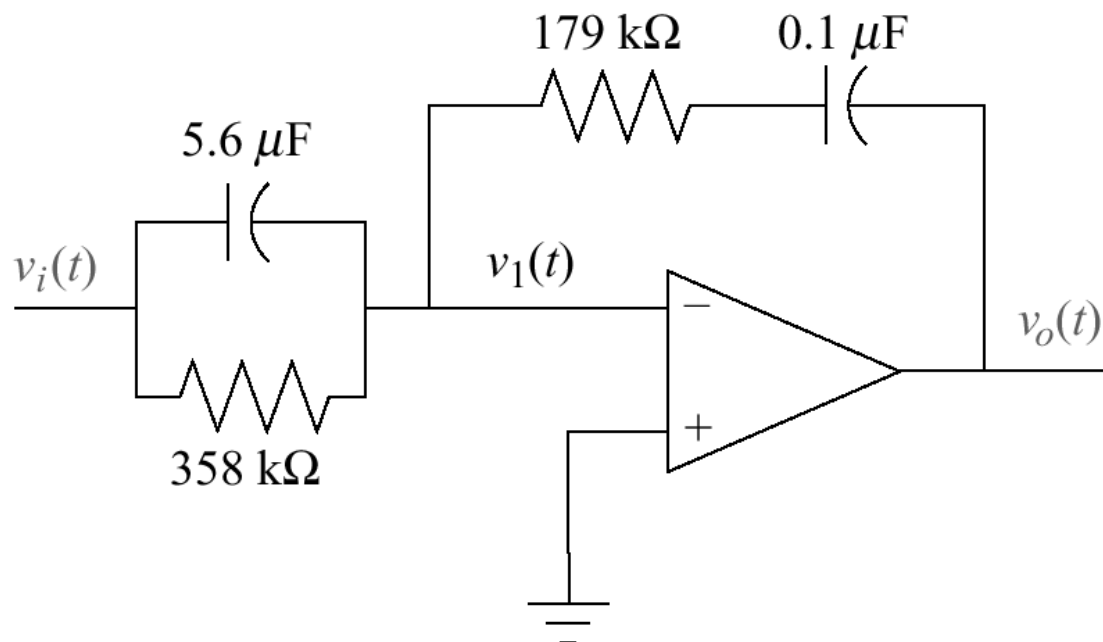


Figure 9.63

Lag-lead compensator
implemented with
cascaded lag and lead
networks with isolation

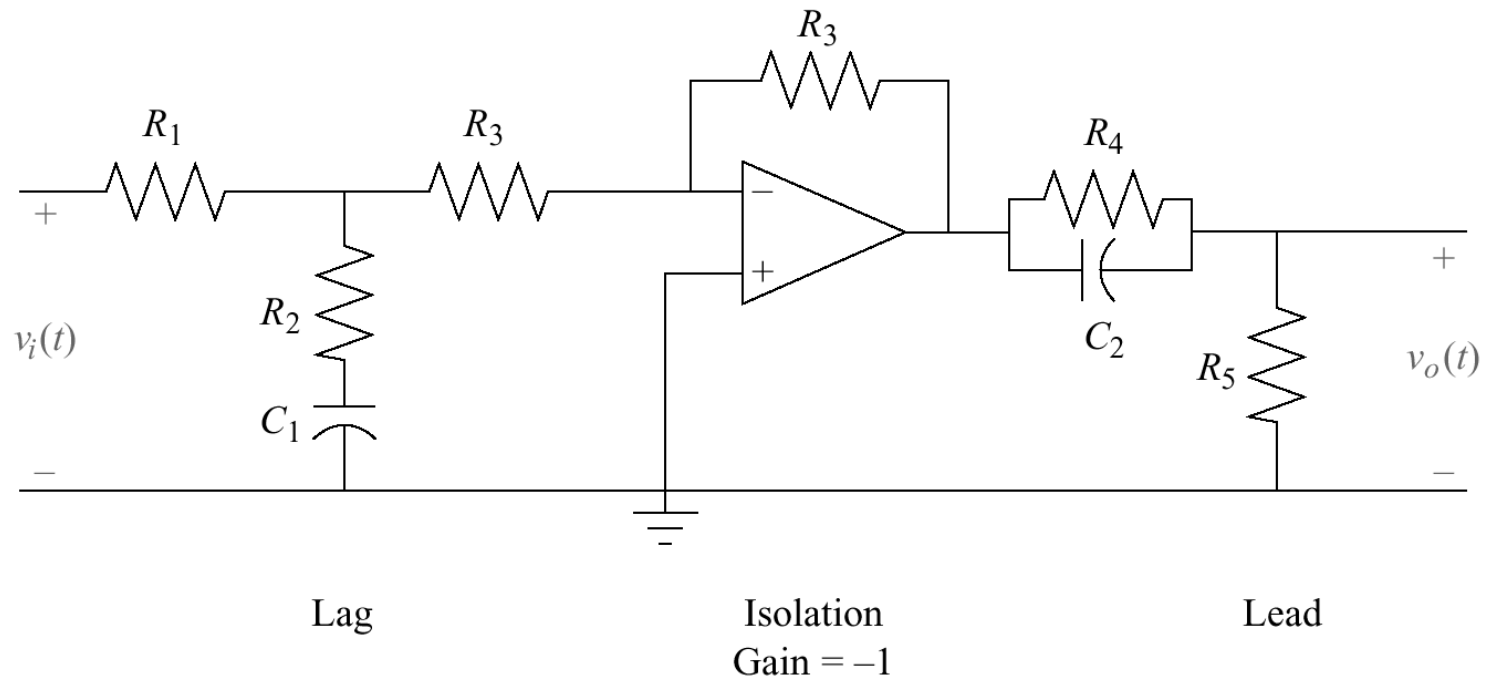
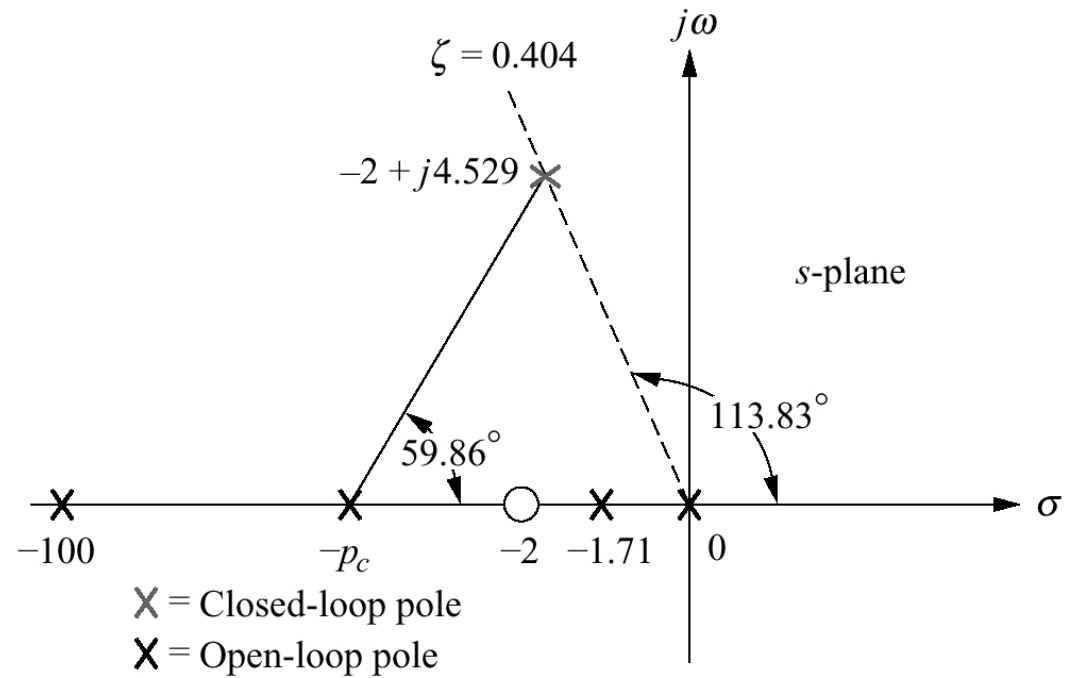


Figure 9.64
Locating compensator pole



Note: This figure is not drawn to scale.

Figure 9.65
Realization of
lag-lead
compensator

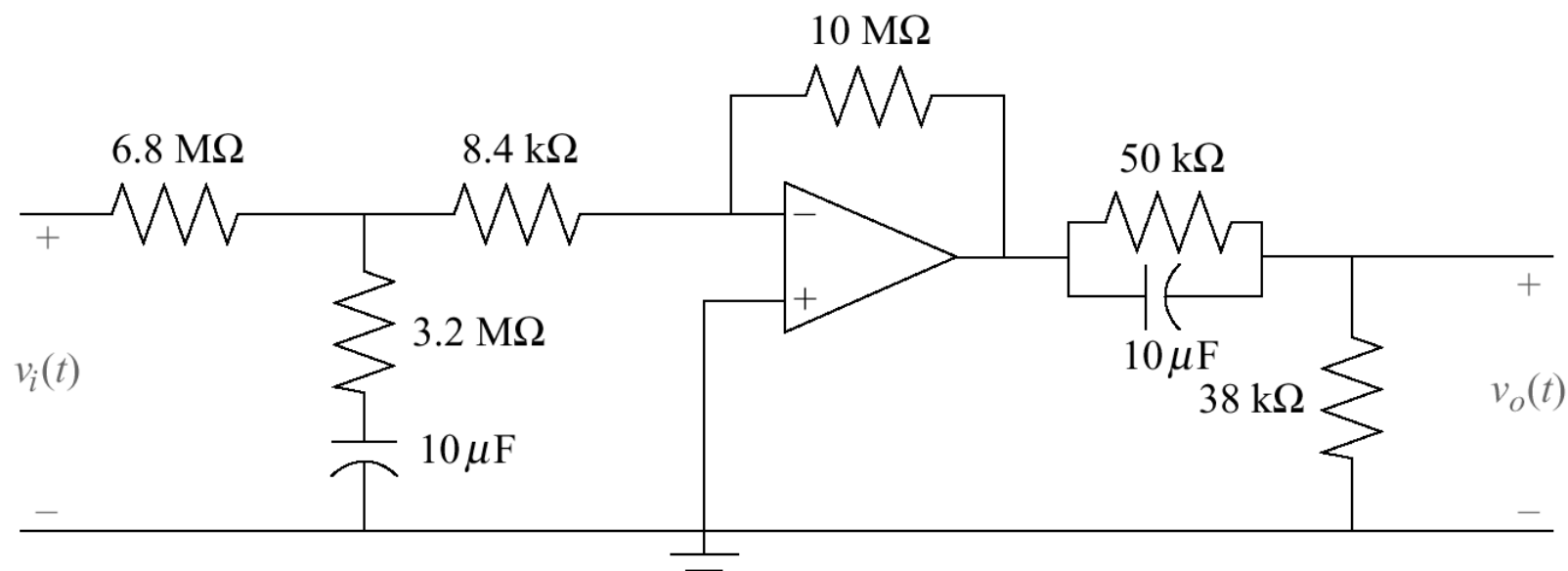


Figure 9.66
Step response of
lag-lead-
compensated
antenna control

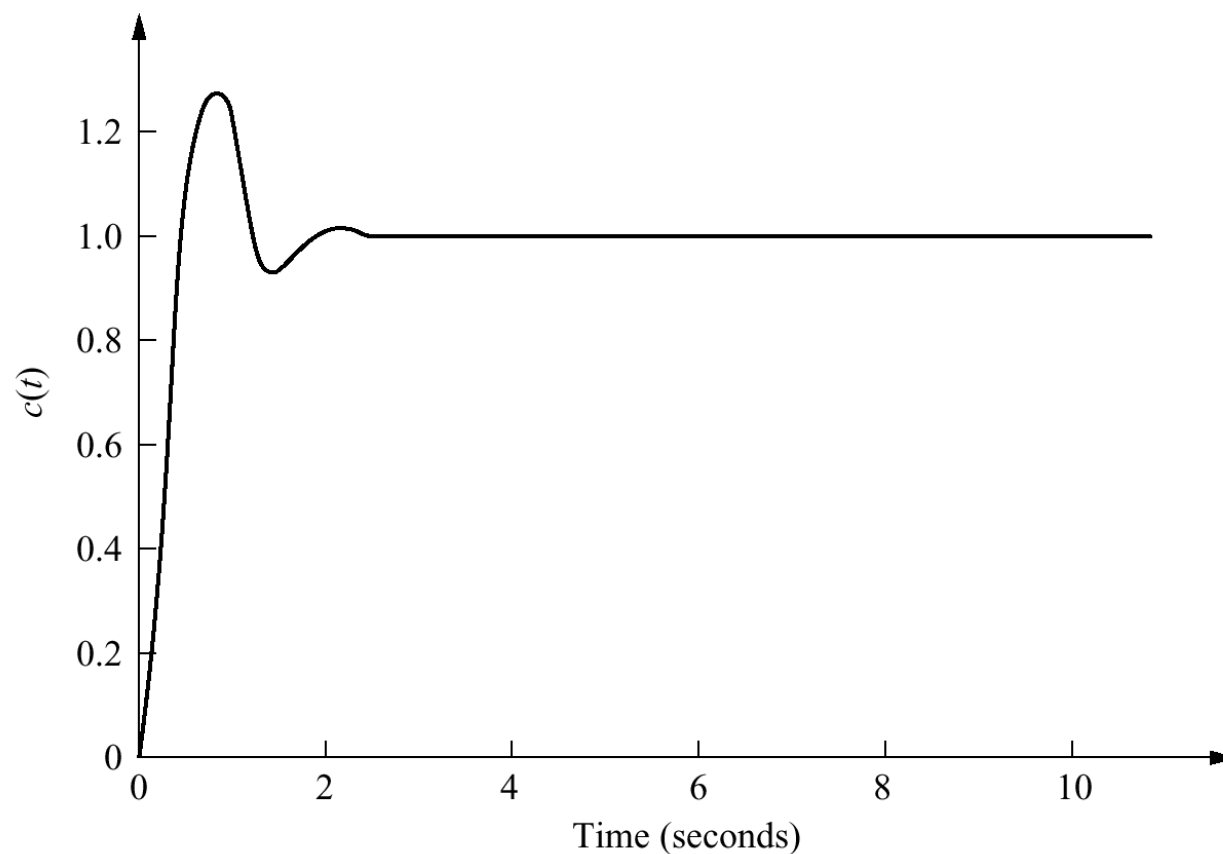
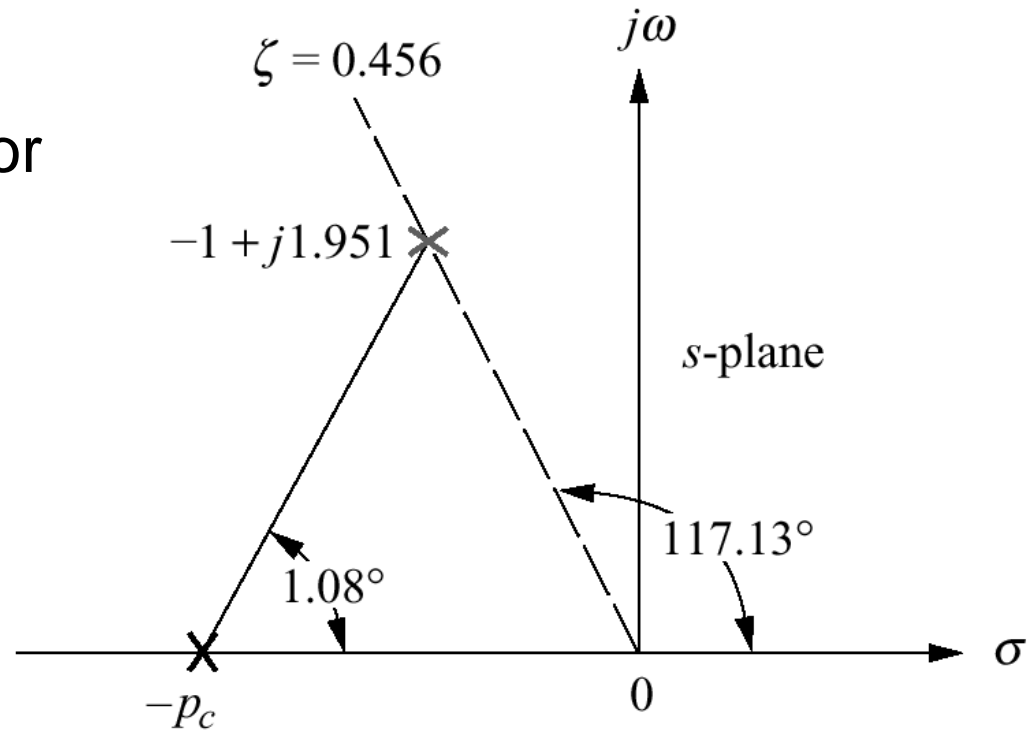


Figure 9.67
Locating compensator pole



\times = Closed-loop pole

\times = Open-loop pole

Note: This figure is not drawn to scale.

Figure 9.68
Root locus for
lead-compensated
system

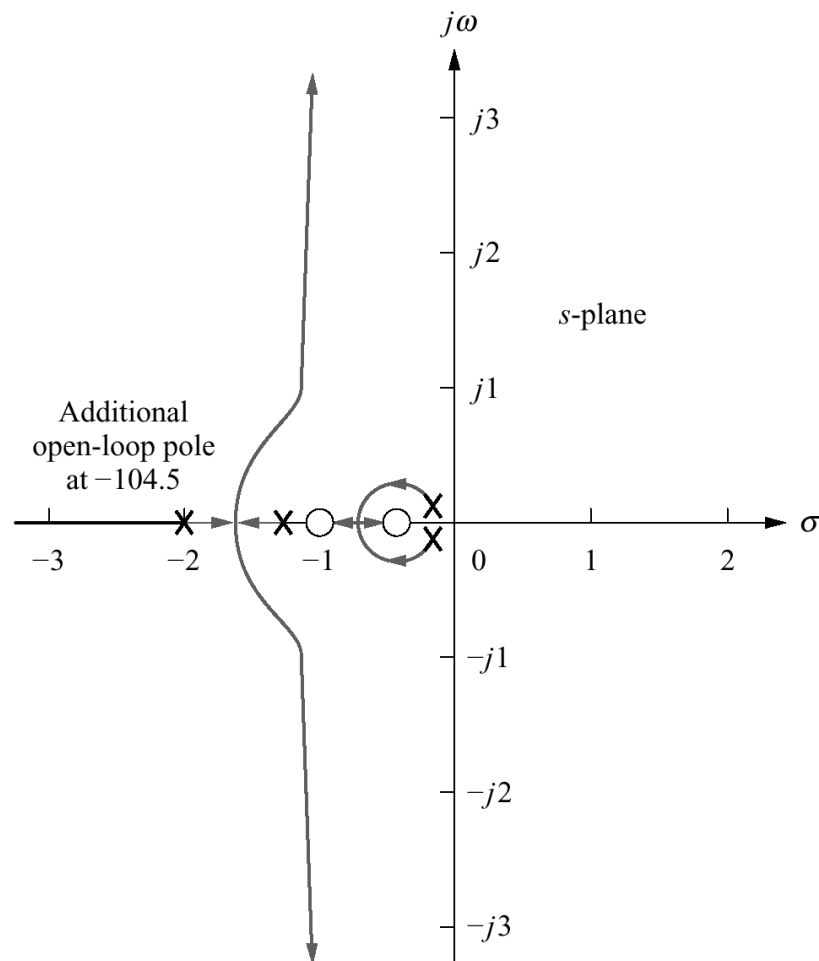


Figure 9.69
Step response of lead-compensated UFSS vehicle

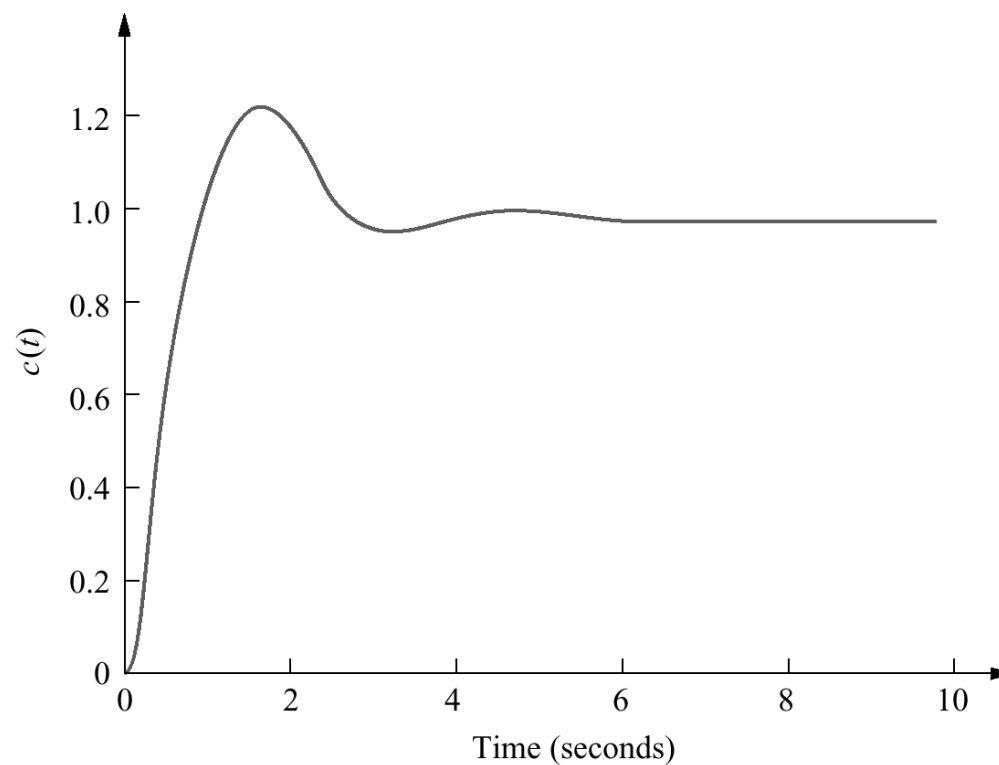


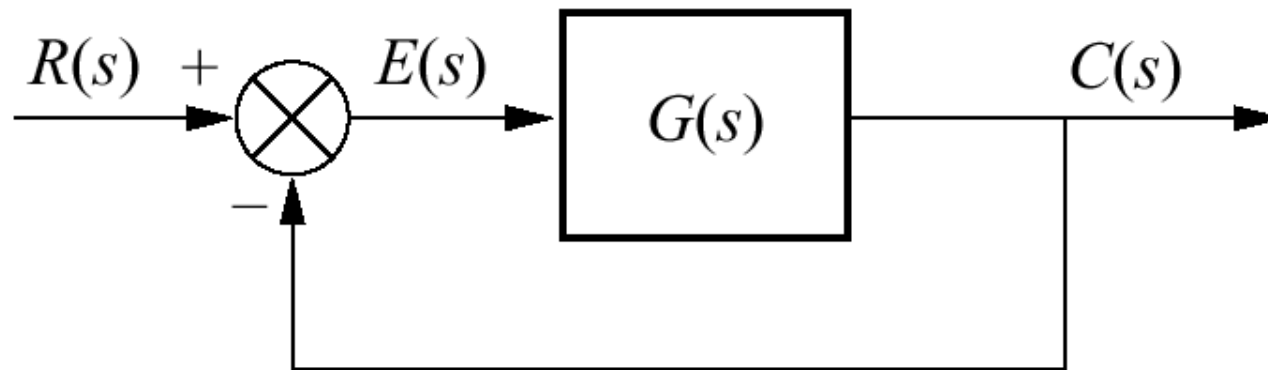
Figure P9.1

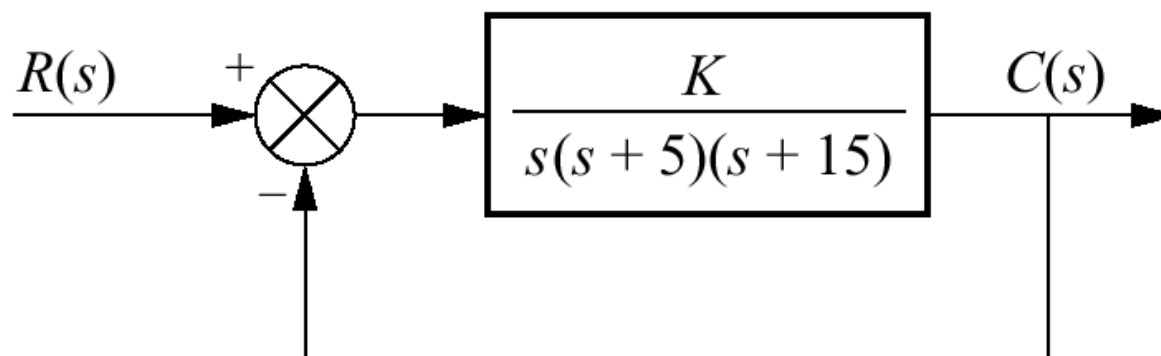
Figure P9.2

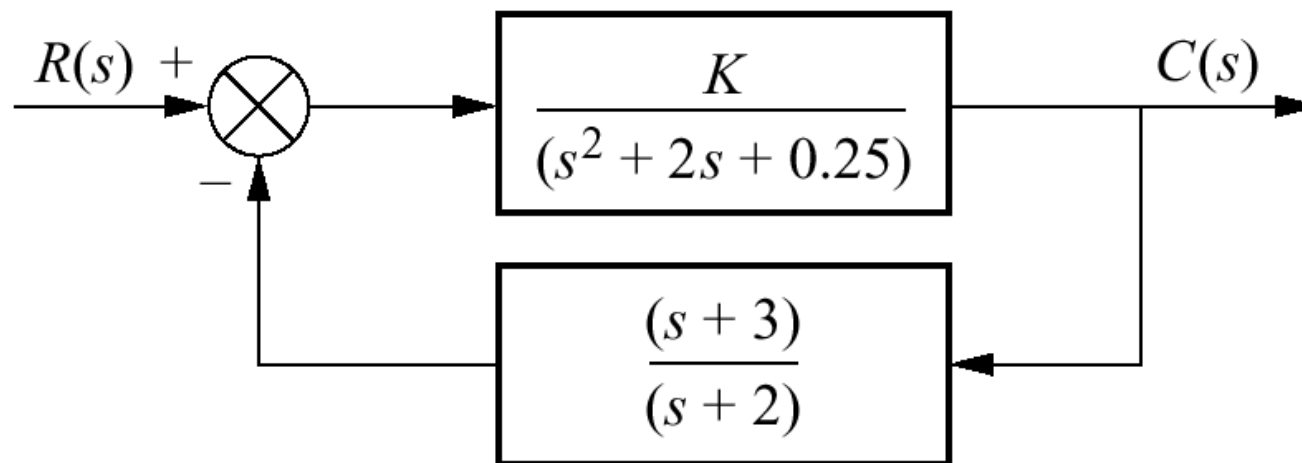
Figure P9.3

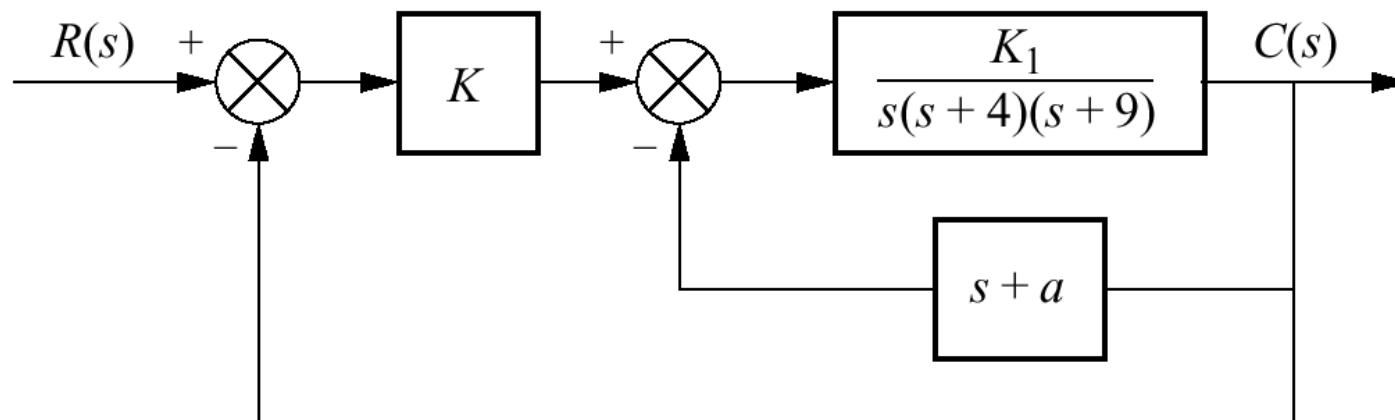
Figure P9.4

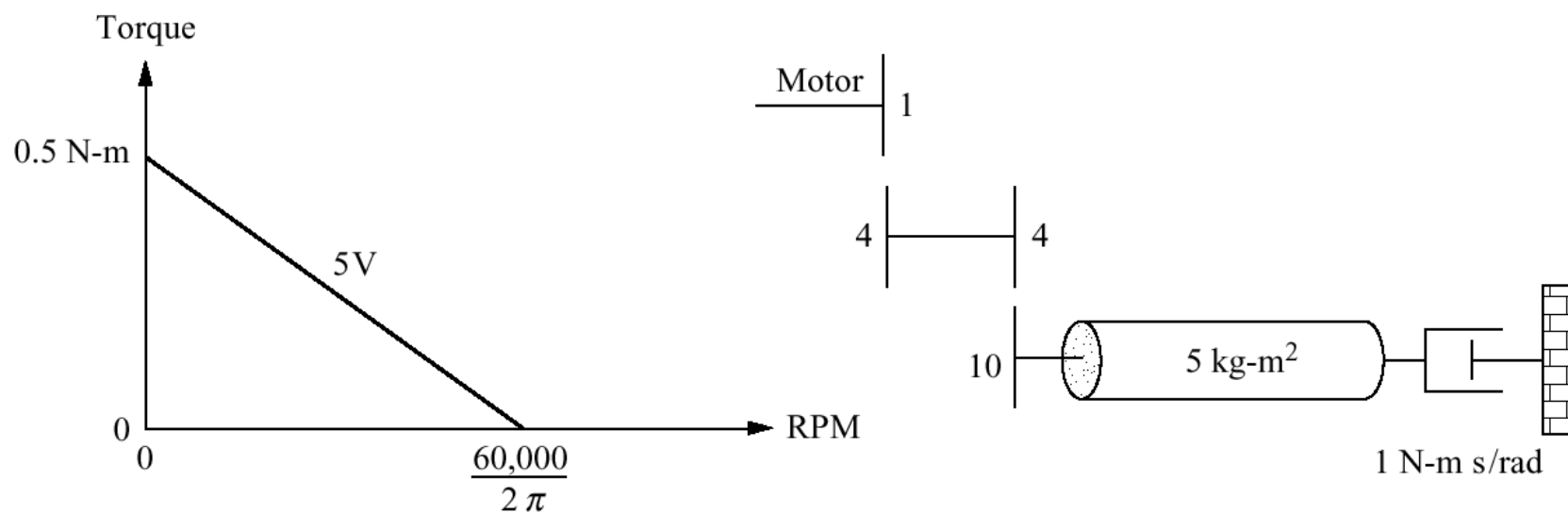
Figure P9.5

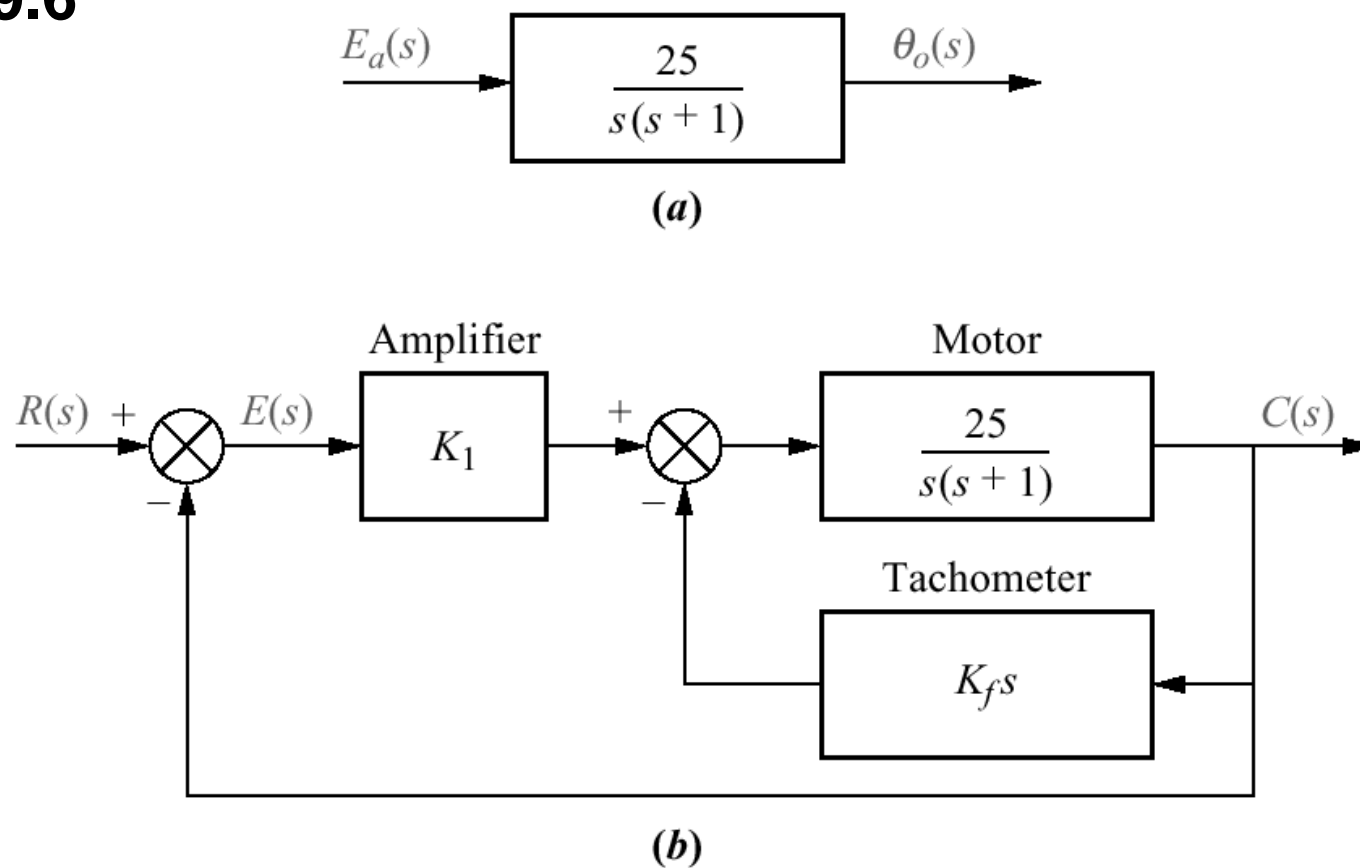
Figure P9.6

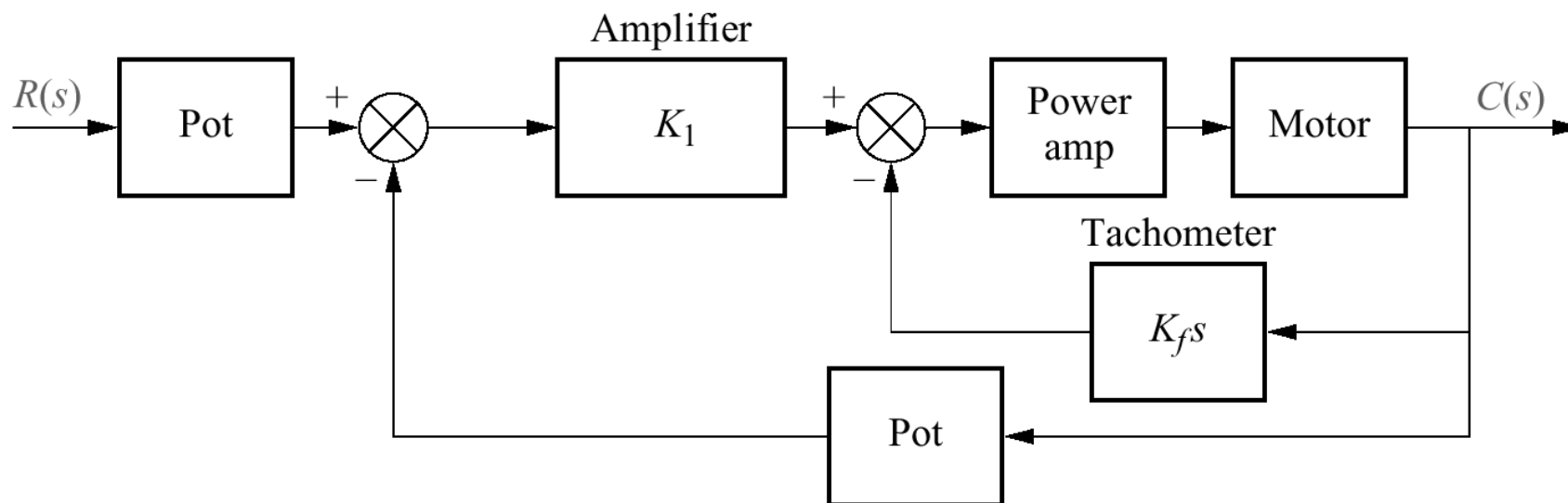
Figure P9.7

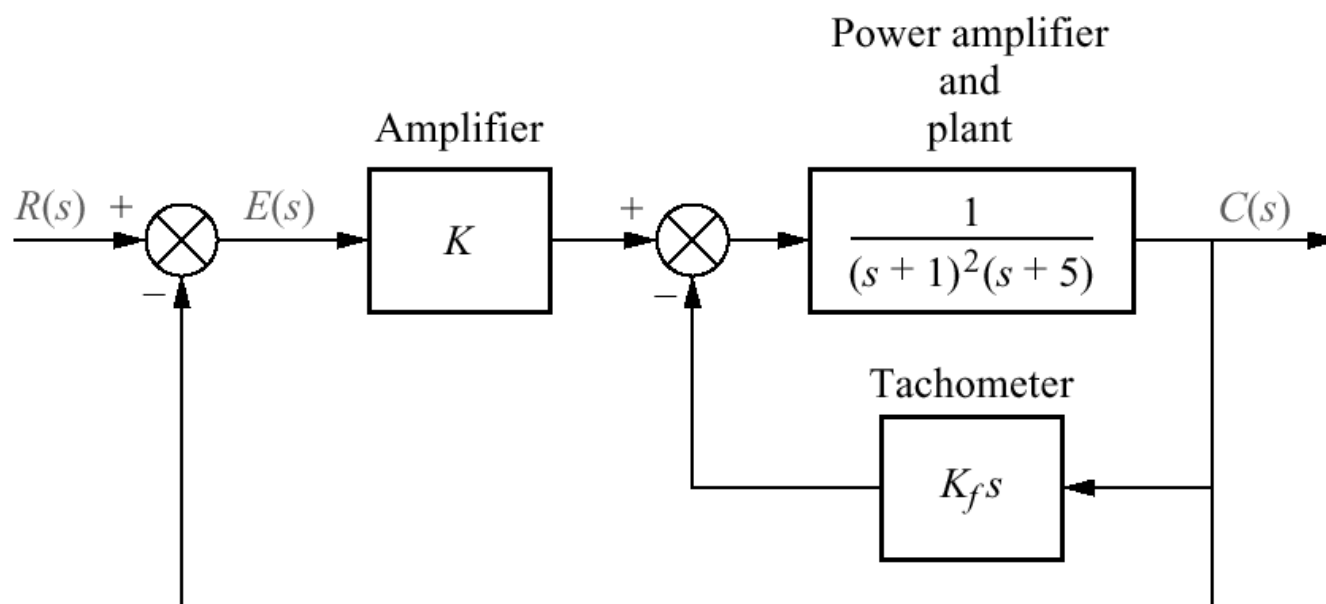
Figure P9.8

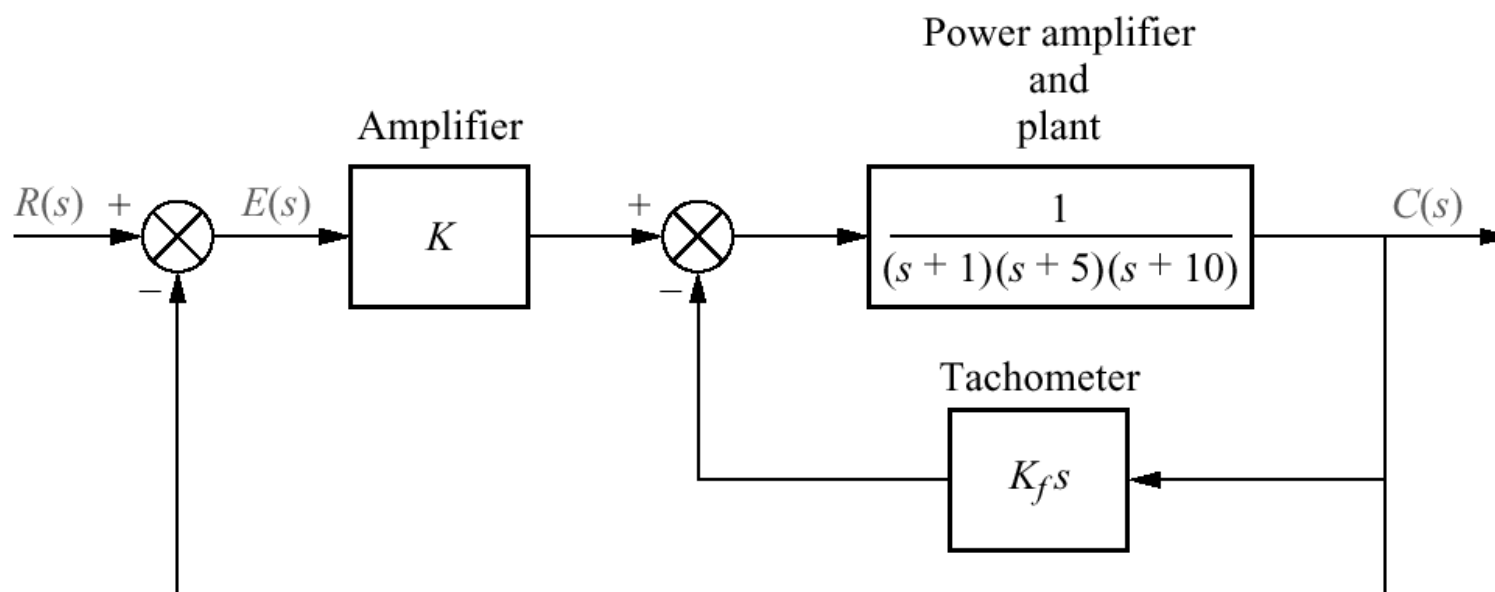
Figure P9.9

Figure P9.10
Chemical process
temperature control
system

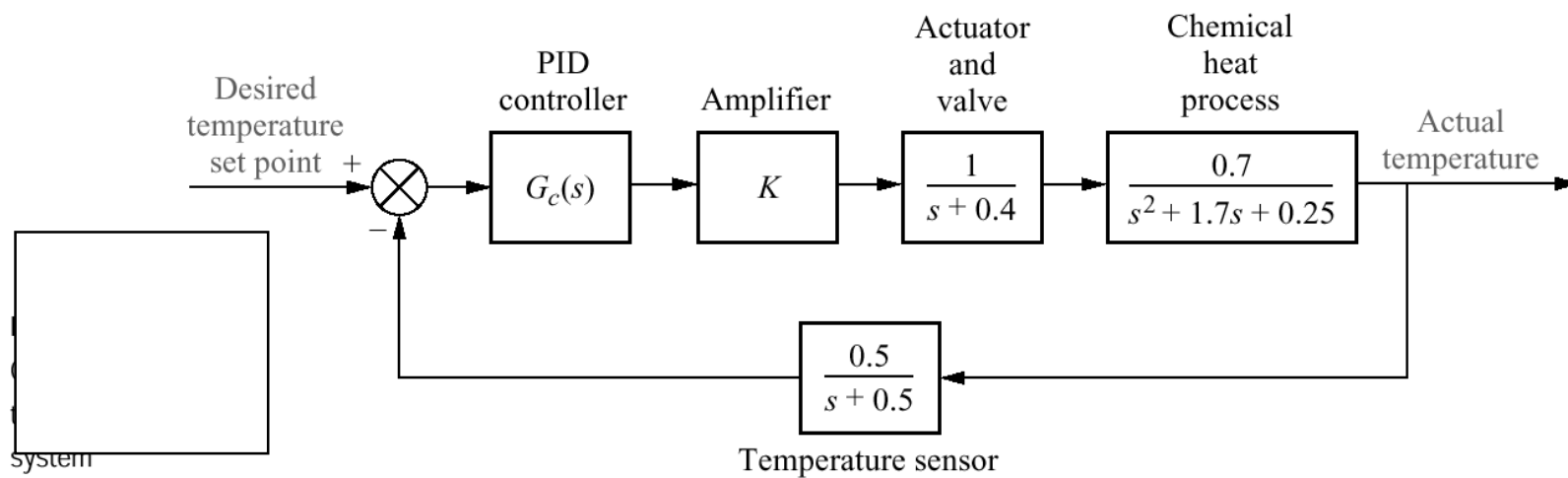


Figure P9.11

a. Magnetic levitation system (©1993 IEEE);
b. block diagram

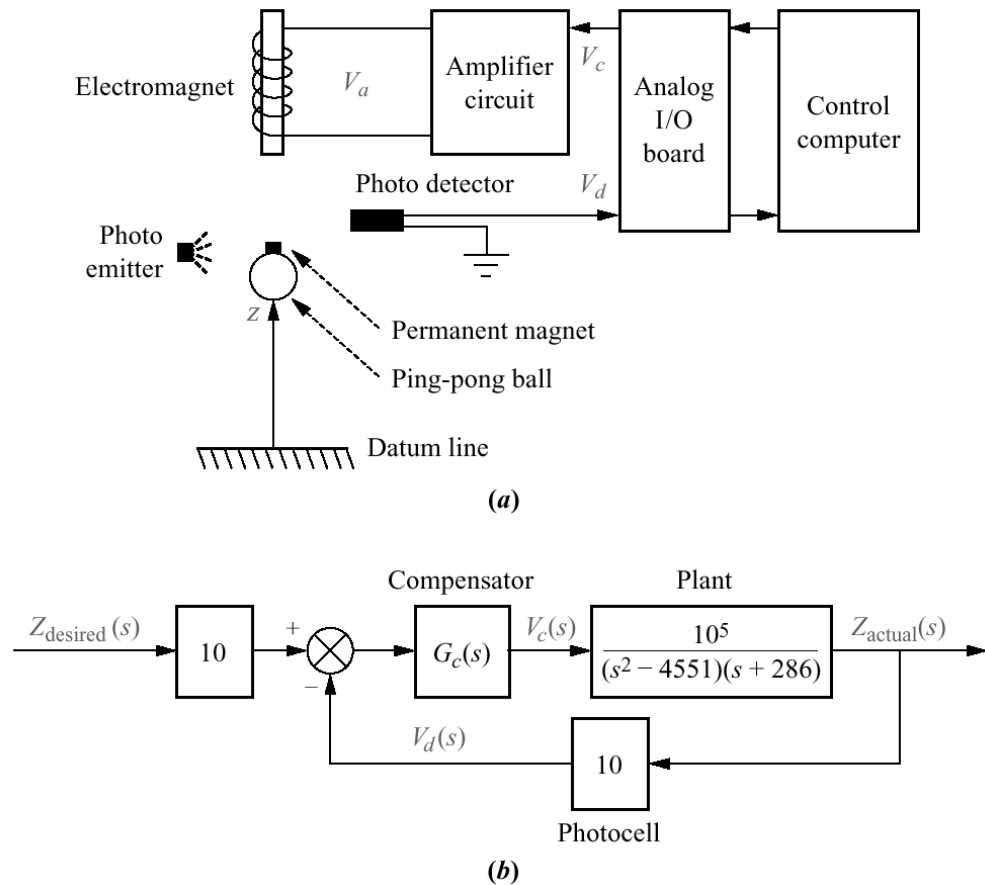


Figure P9.12
Simplified block
diagram for angle of
attack control

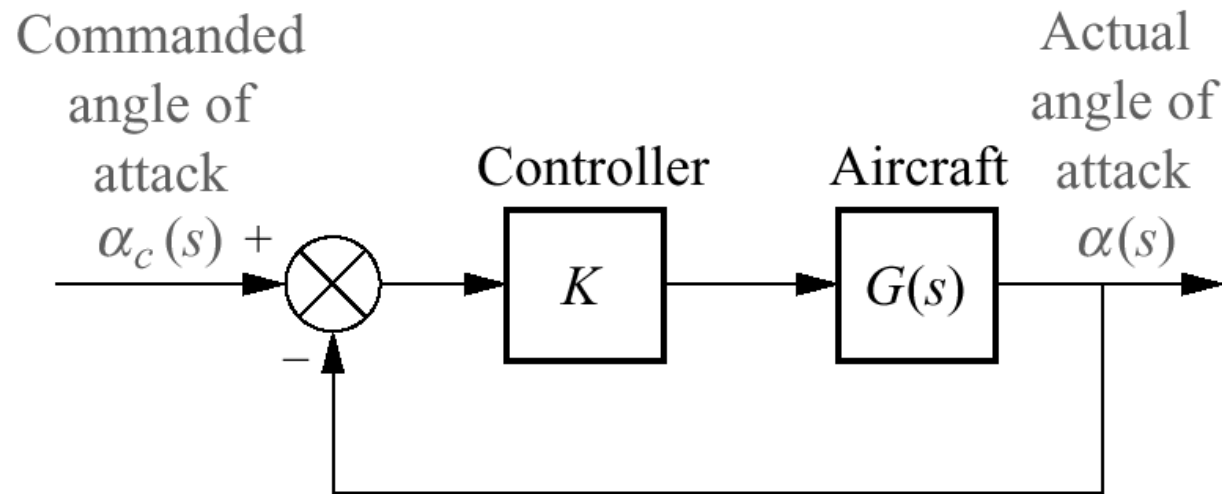


Figure P9.13

Simplified block diagram of a self-guiding vehicle's bearing angle control

