Table 7.1
Test waveforms for evaluating steady-state errors of position control systems

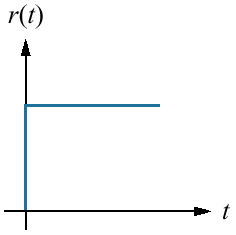
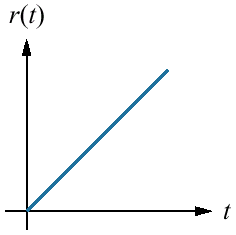
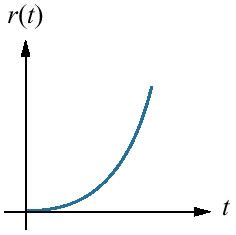
Waveform	Name	Physical interpretation	Time function	Laplace transform
	Step	Constant position	1	$\frac{1}{s}$
	Ramp	Constant velocity	t	$\frac{1}{s^2}$
	Parabola	Constant acceleration	$\frac{1}{2}t^2$	$\frac{1}{s^3}$

Figure 7.1
Test inputs for steady-state error analysis and design vary with target type

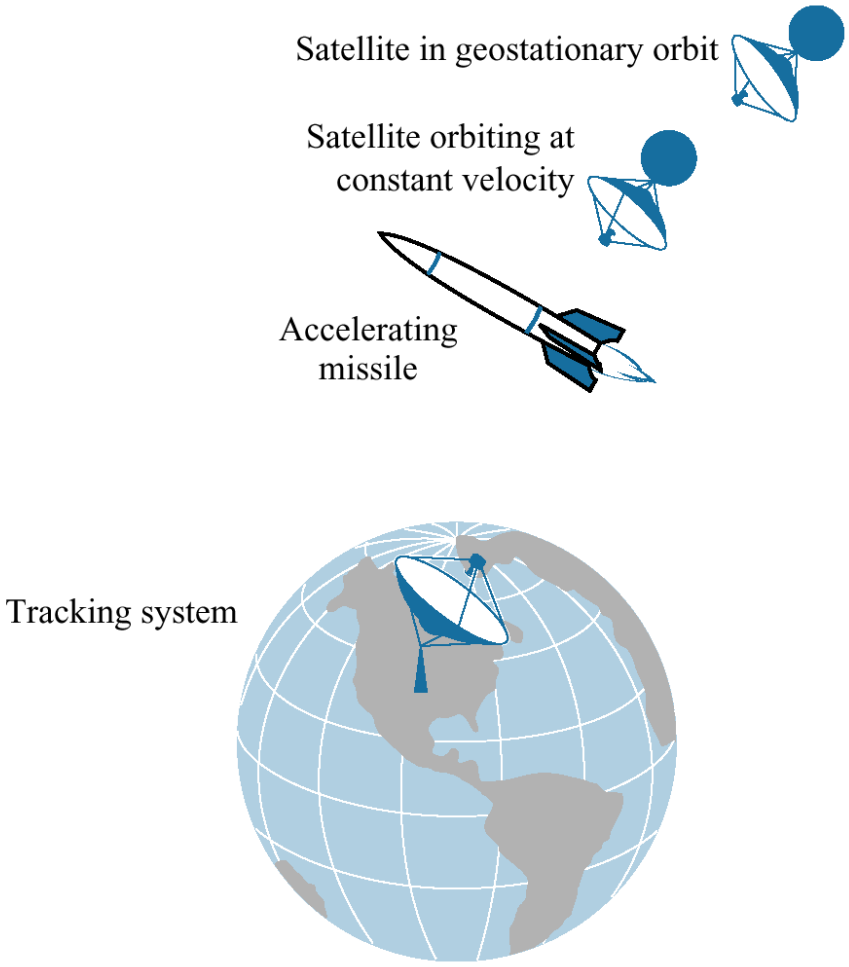


Figure 7.2
Steady-state error:
a. step input;
b. ramp input

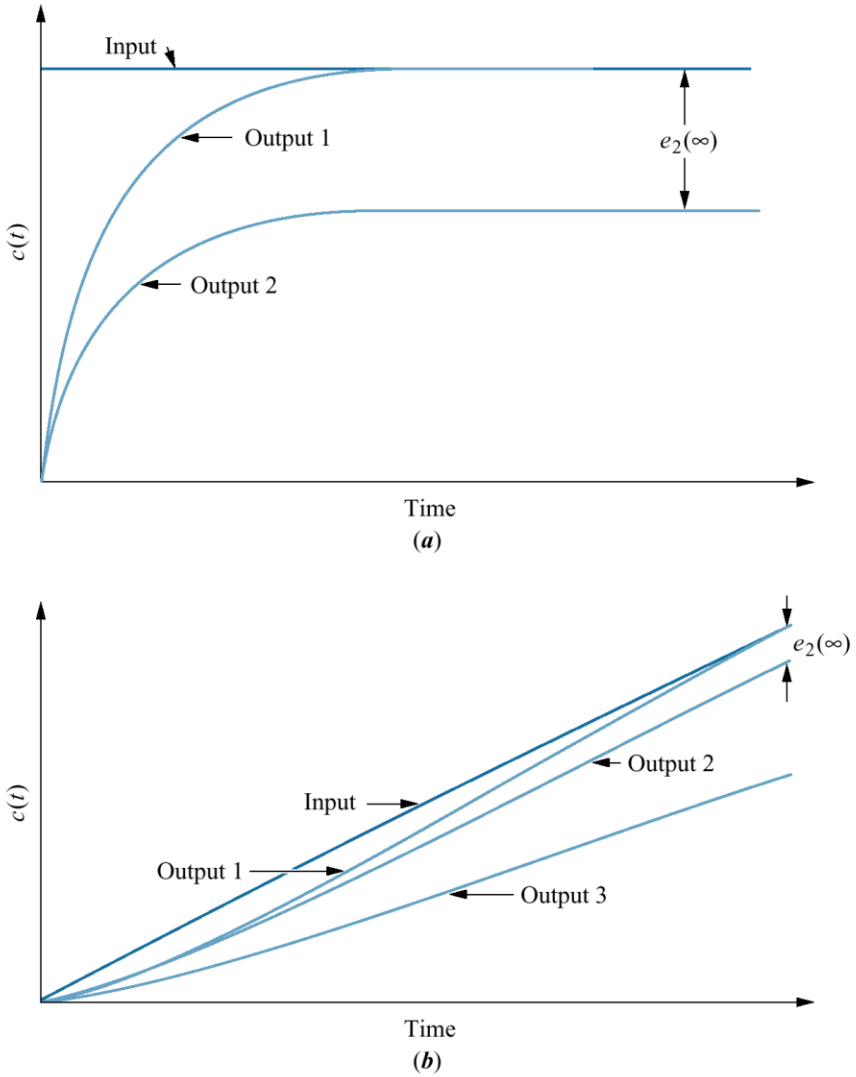


Figure 7.3
Closed-loop control system error:
a. general representation;
b. representation for unity feedback systems

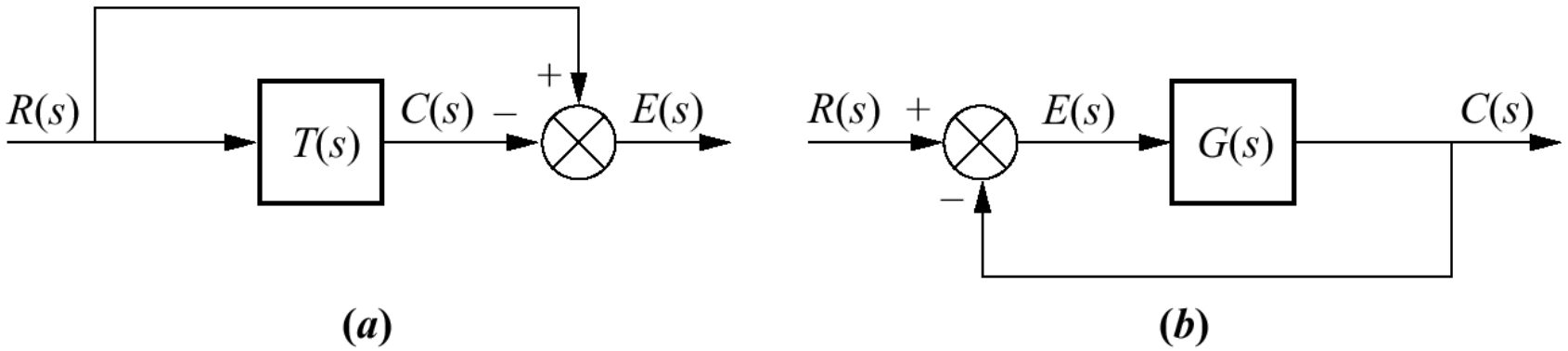


Figure 7.4
System with:
a. finite steady-state error for a step input;
b. zero steady-state error for step input

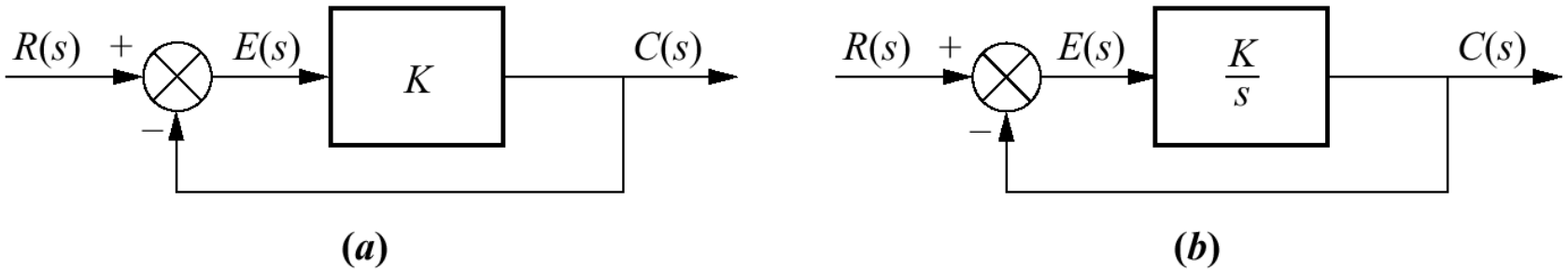


Figure 7.5
Feedback
control system for
Example 7.2

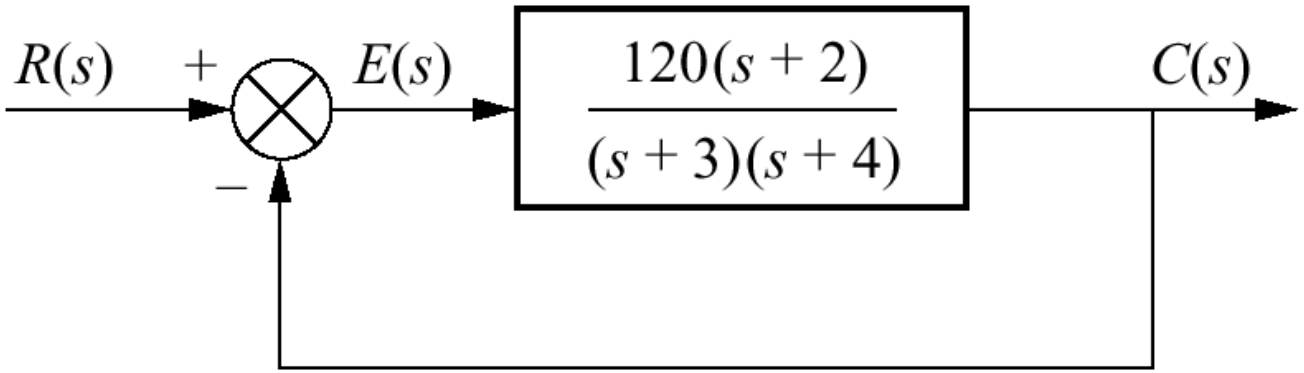


Figure 7.6
Feedback
control system for
Example 7.3

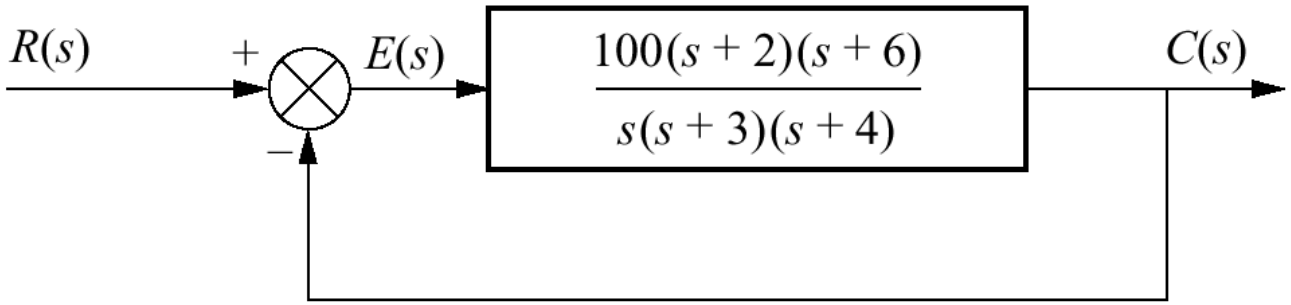


Figure 7.7 Feedback control systems for Example 7.4

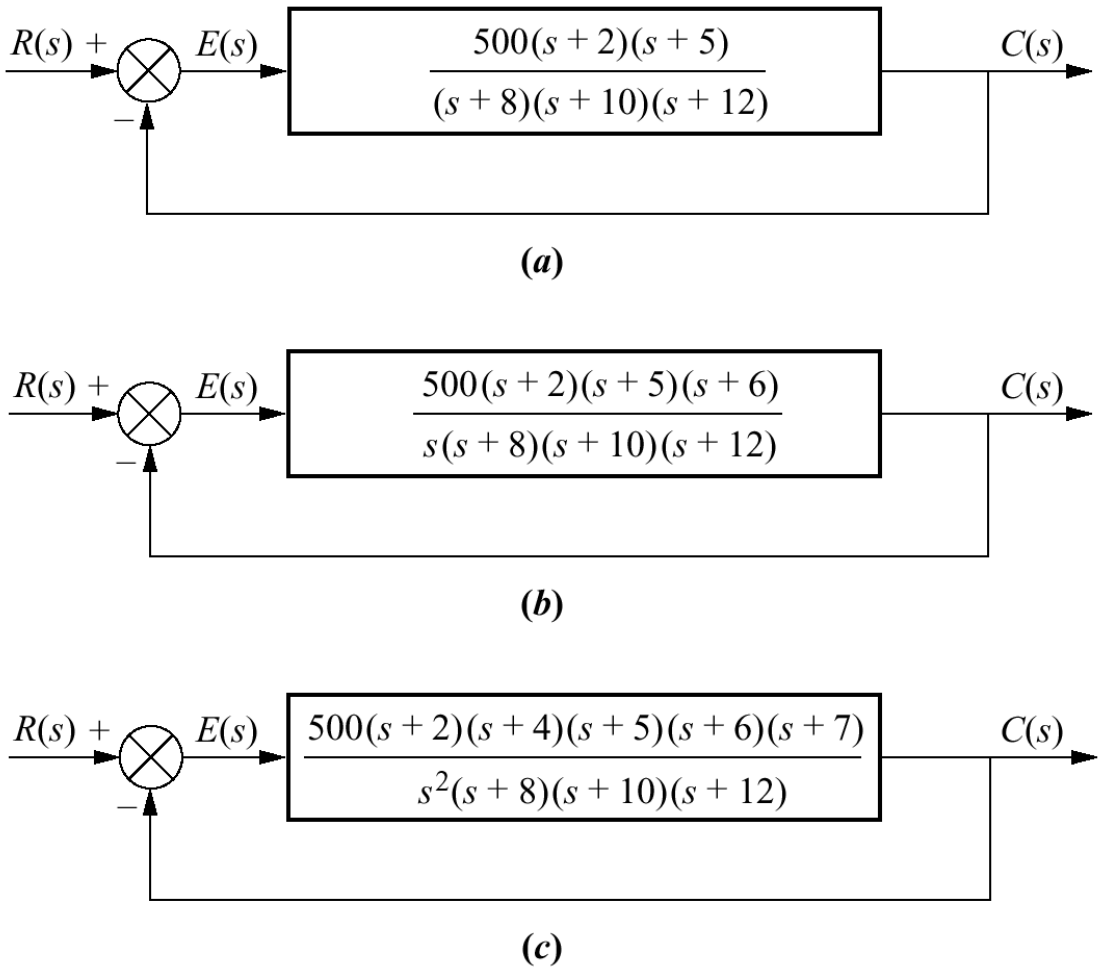


Figure 7.8
Feedback control system for defining system type

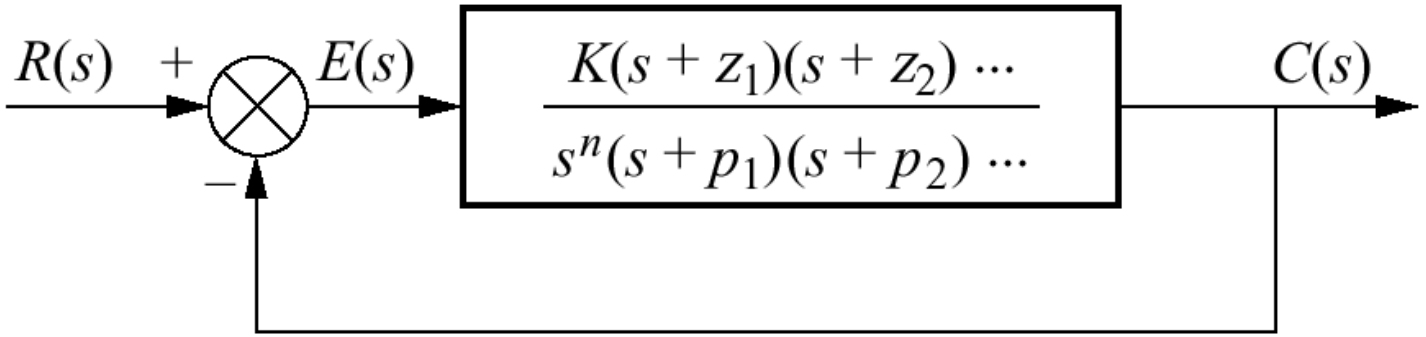


Table 7.2
Relationships between input, system type, static error constants, and steady-state errors

Input	Steady-state error formula	Type 0		Type 1		Type 2	
		Static error constant	Error	Static error constant	Error	Static error constant	Error
Step, $u(t)$	$\frac{1}{1+K_p}$	$K_p =$ Constant	$\frac{1}{1+K_p}$	$K_p = \infty$	0	$K_p = \infty$	0
Ramp, $tu(t)$	$\frac{1}{K_v}$	$K_v = 0$	∞	$K_v =$ Constant	$\frac{1}{K_v}$	$K_v = \infty$	0
Parabola, $\frac{1}{2}t^2u(t)$	$\frac{1}{K_a}$	$K_a = 0$	∞	$K_a = 0$	∞	$K_a =$ Constant	$\frac{1}{K_a}$

Figure 7.9
A robot used in the manufacturing of semiconductor random-access memories (RAMs) similar to those in personal computers. Steady-state error is an important design consideration for assembly-line robots.

Figure 7.10
Feedback
control system
for Example 7.6

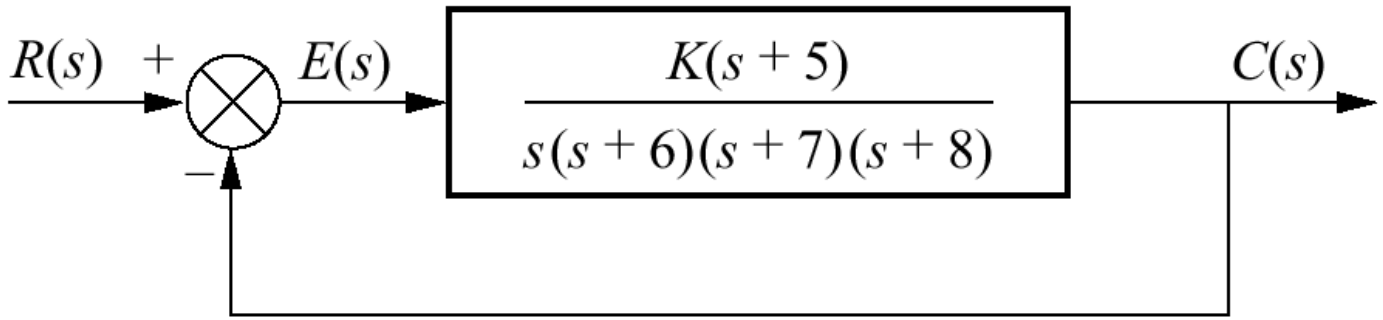


Figure 7.11
Feedback control system showing disturbance

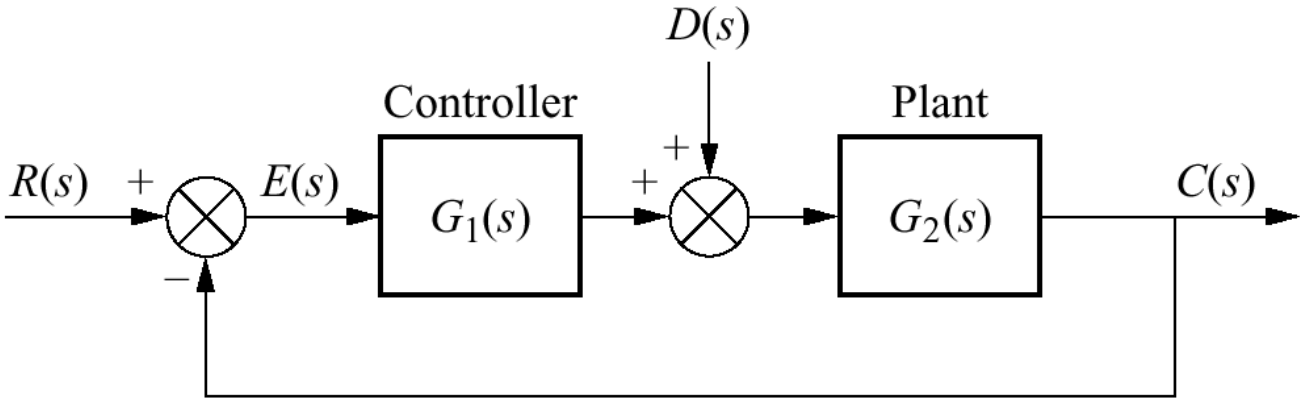


Figure 7.12
Figure 7.11 system rearranged to show disturbance as input and error as output, with R(s) = 0

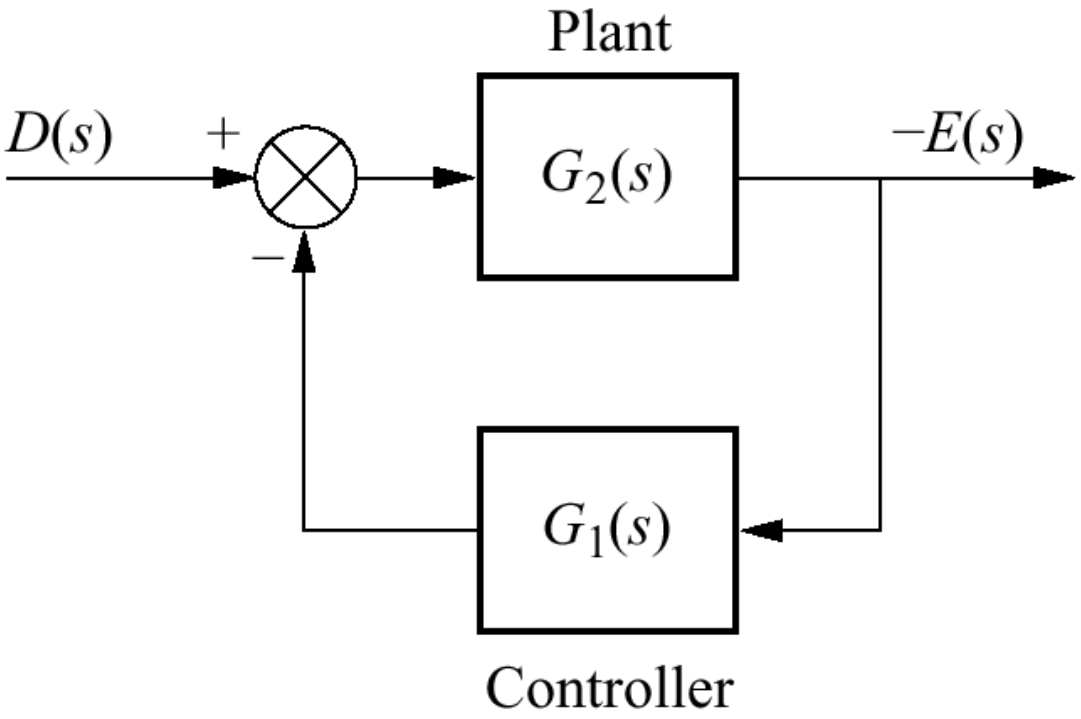


Figure 7.13
Feedback control system for
Example 7.7

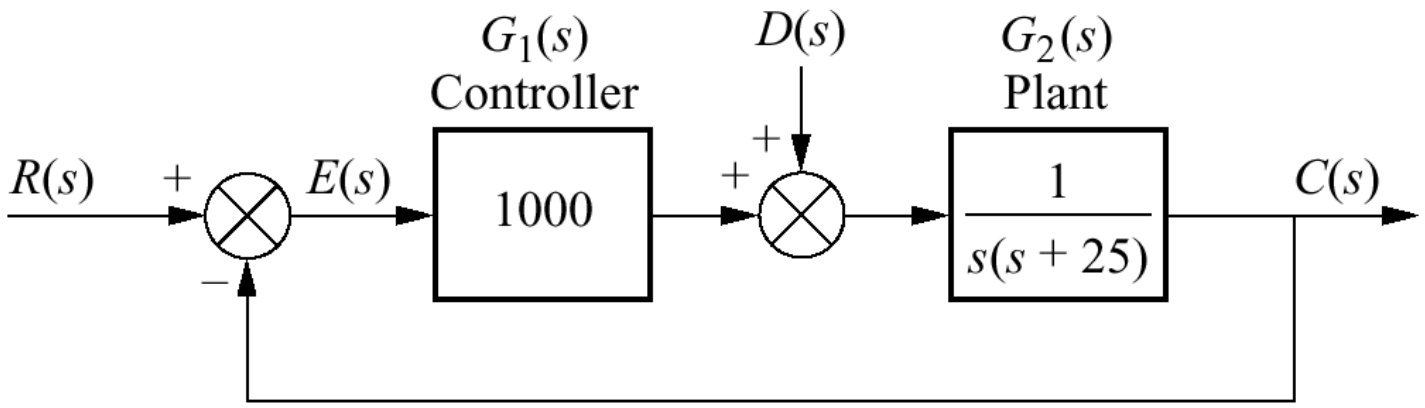


Figure 7.14
System for
Skill-Assessment
Exercise 7.4

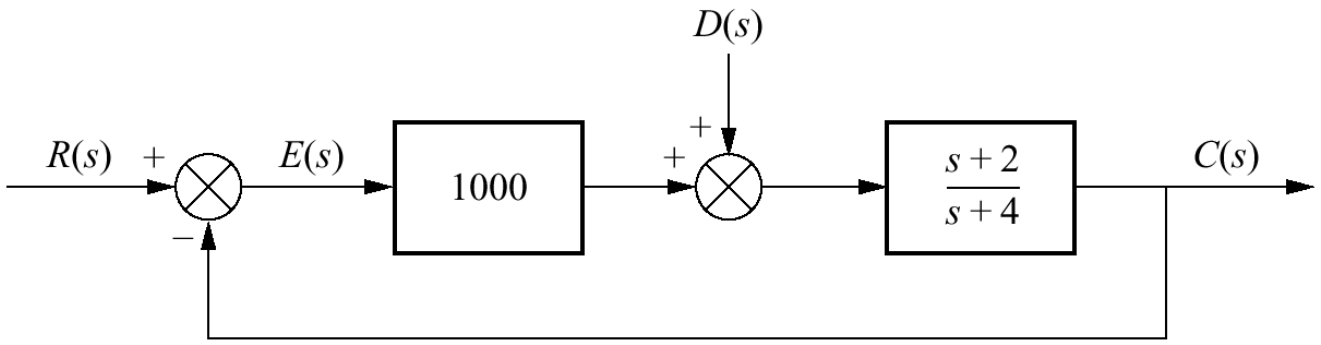


Figure 7.15
Forming an equivalent unity feedback system from a general nonunity feedback system

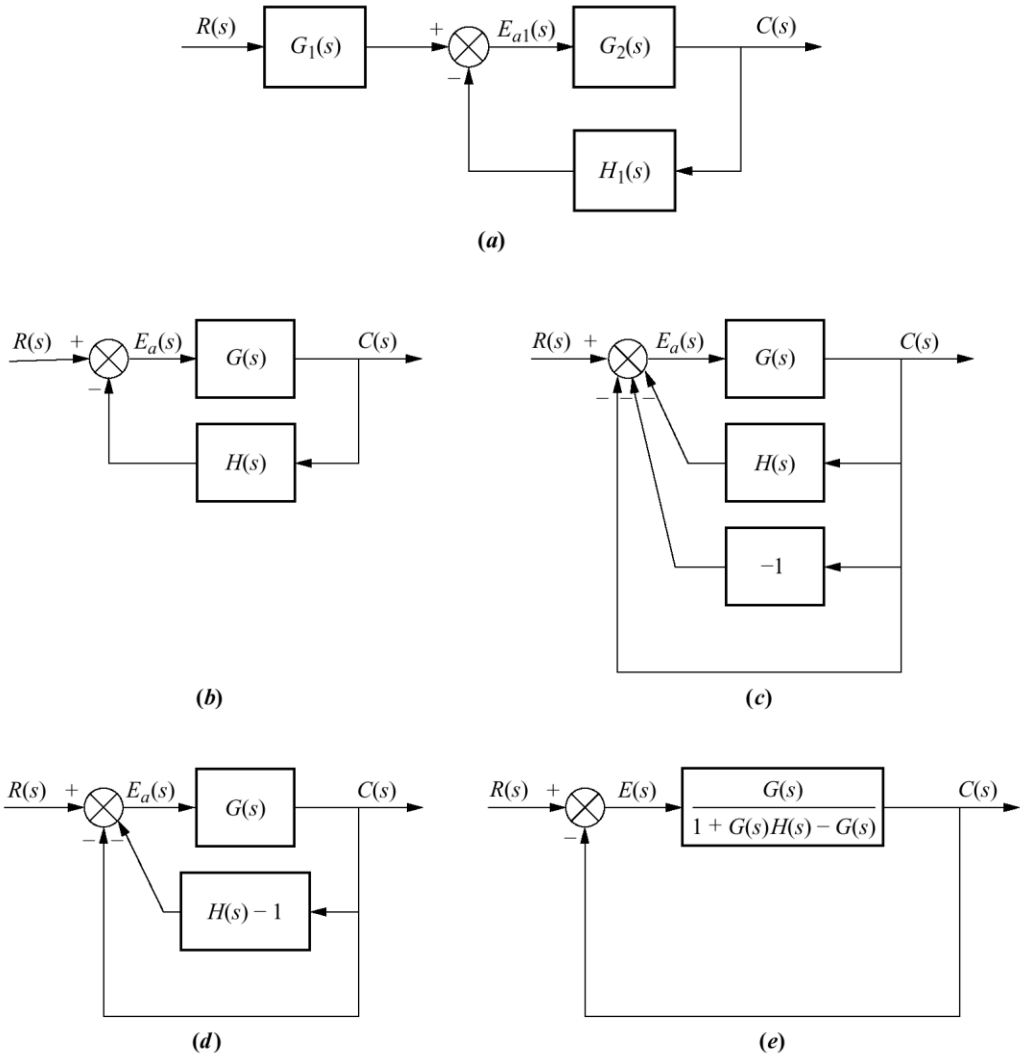


Figure 7.16
Nonunity feedback control system for Example 7.8

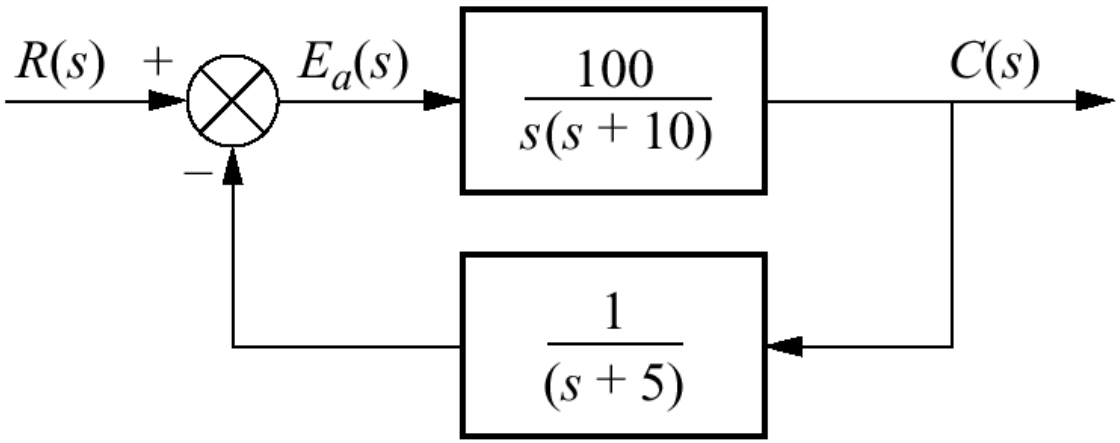


Figure 7.17
Nonunity feedback control system with disturbance

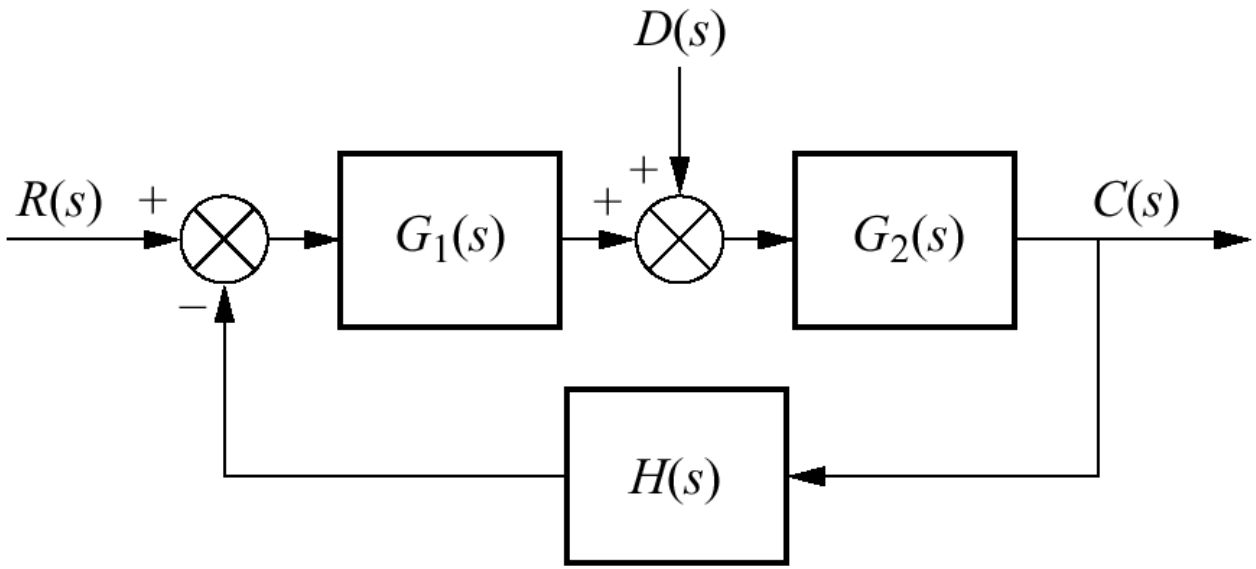


Figure 7.18
Nonunity feedback system for Skill-Assessment Exercise 7.5

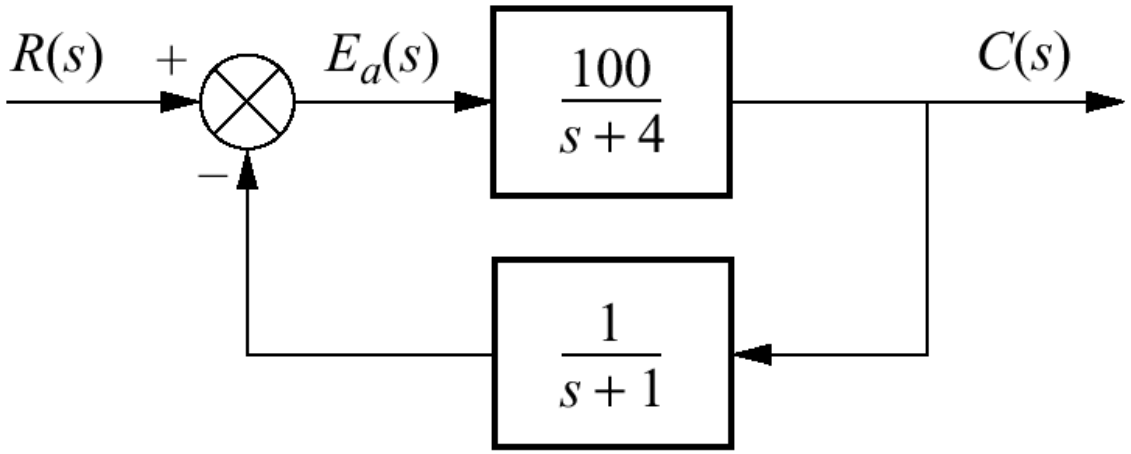


Figure 7.19
Feedback control system for Examples 7.10 and 7.11

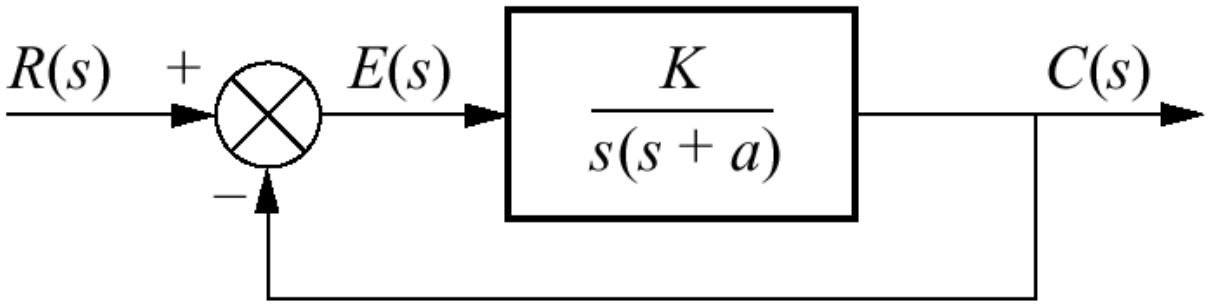


Figure 7.20
Feedback
control system
for Example 7.12

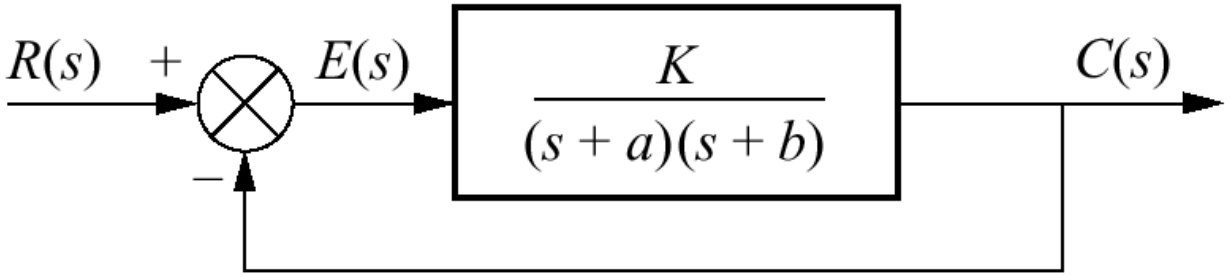


Figure 7.21
System for
Skill-Assessment
Exercise 7.6

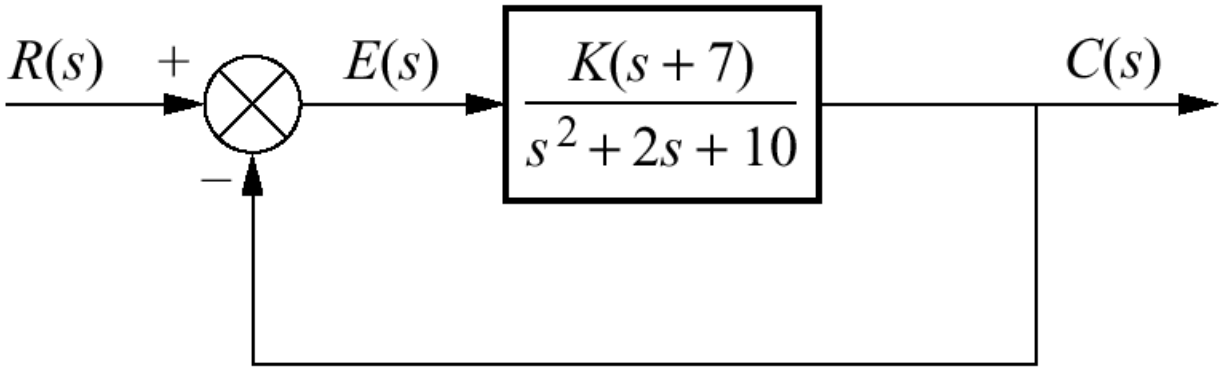


Figure 7.22
Video laser disc recording:
control system for focusing write beam

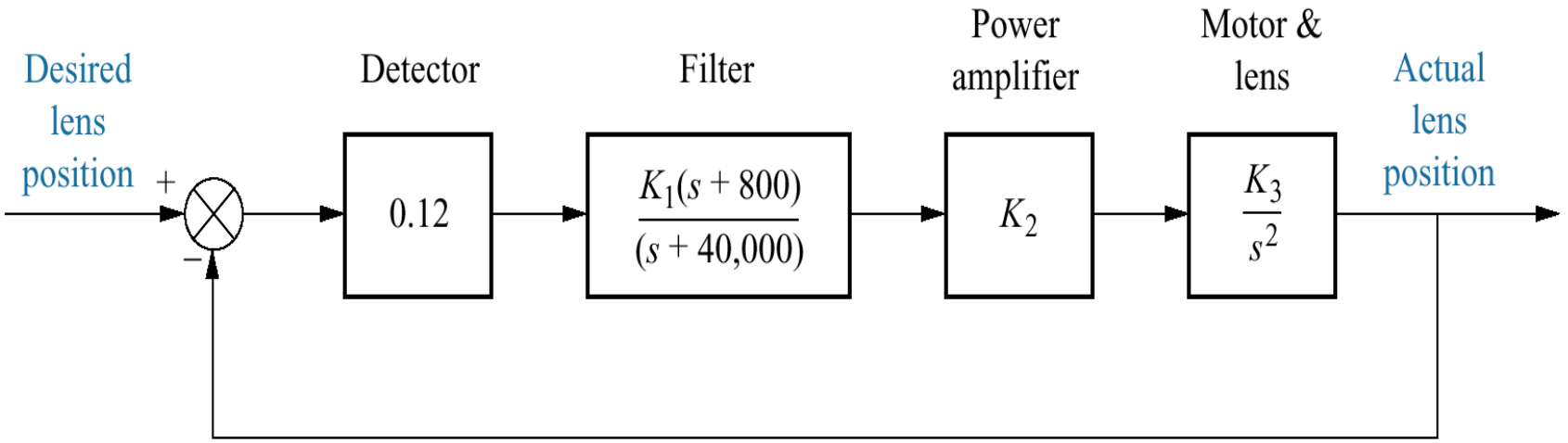


Figure 7.23
Video disc laser recording:
a. focus detector optics;
b. linearized transfer function for focus detector

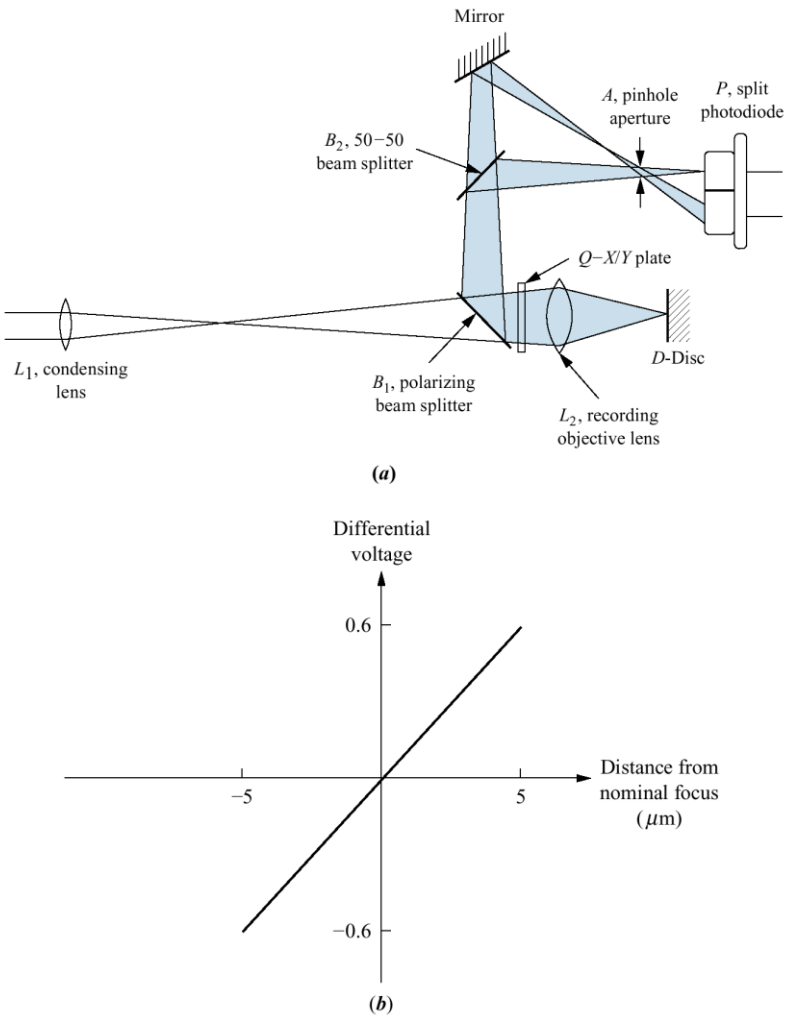


Figure 7.24
Video laser disc recording focusing system

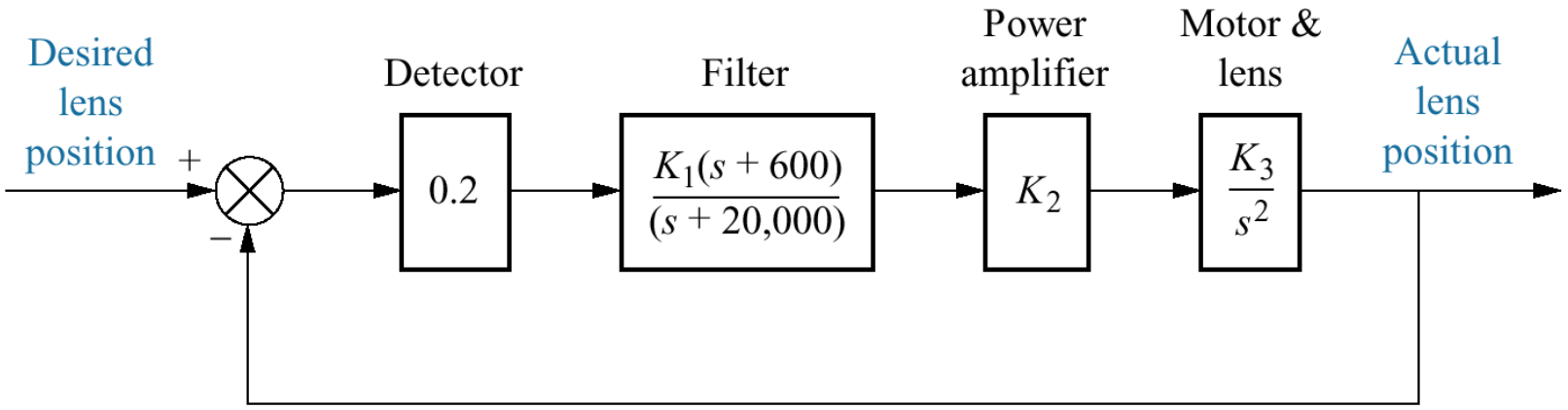


Table 7.1
Test waveforms for evaluating steady-state errors of position control systems

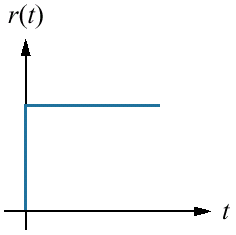
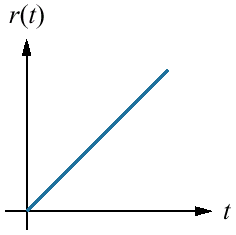
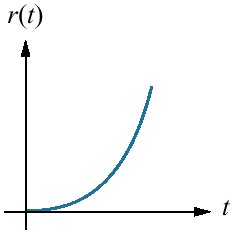
Waveform	Name	Physical interpretation	Time function	Laplace transform
	Step	Constant position	1	$\frac{1}{s}$
	Ramp	Constant velocity	t	$\frac{1}{s^2}$
	Parabola	Constant acceleration	$\frac{1}{2}t^2$	$\frac{1}{s^3}$

Figure 7.1
Test inputs for steady-state error analysis and design vary with target type

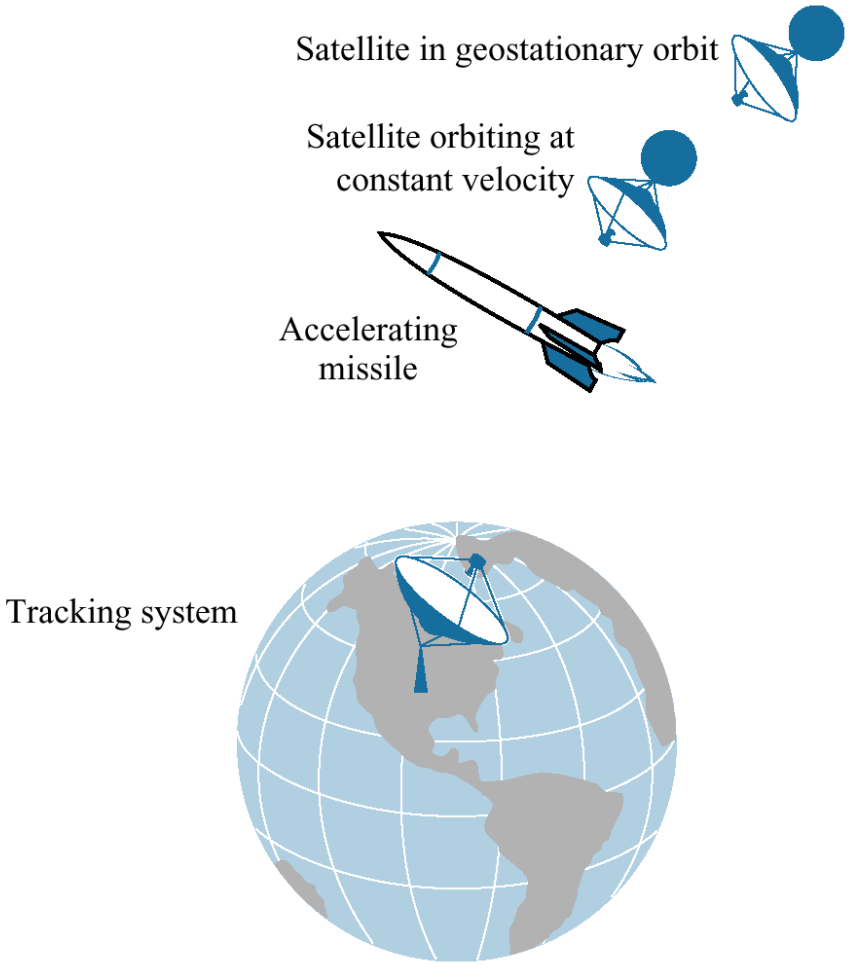


Figure 7.2
Steady-state error:
a. step input;
b. ramp input

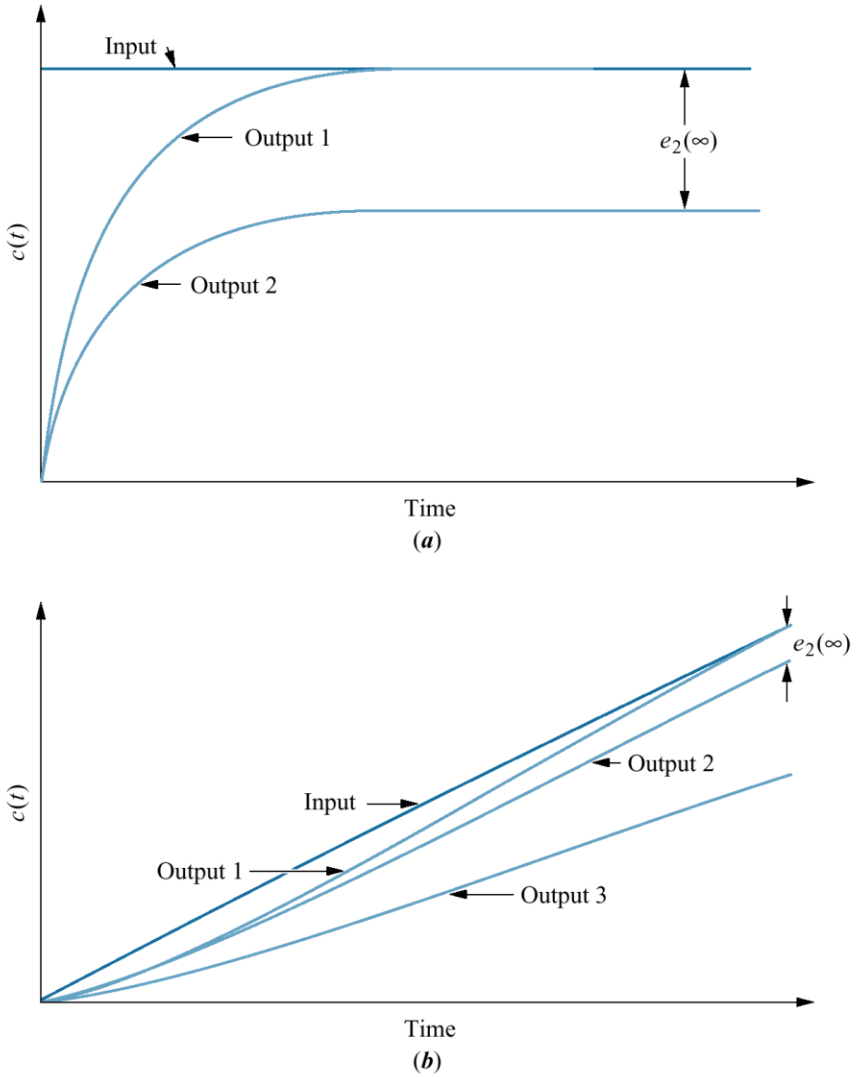


Figure 7.3
Closed-loop control system error:
a. general representation;
b. representation for unity feedback systems

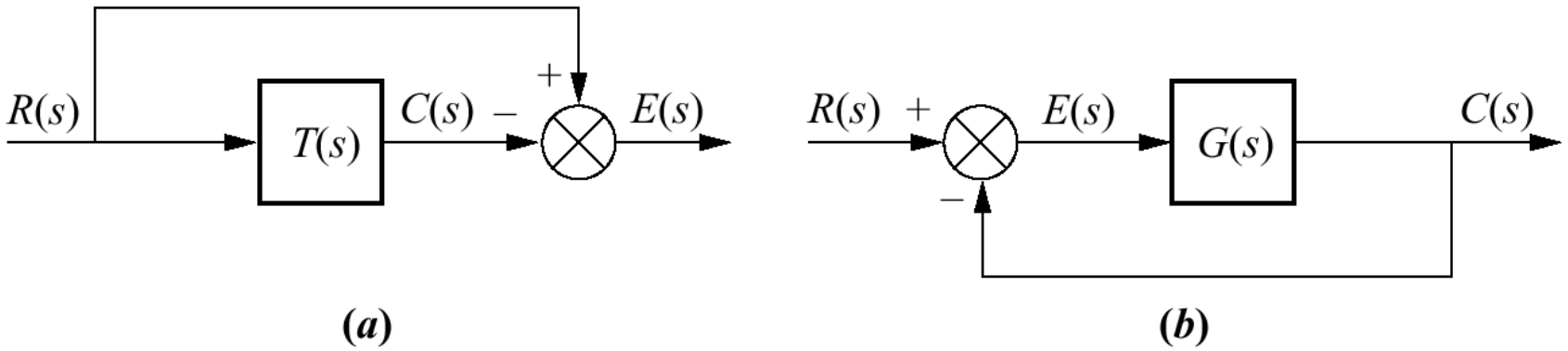


Figure 7.4
System with:
a. finite steady-state error for a step input;
b. zero steady-state error for step input

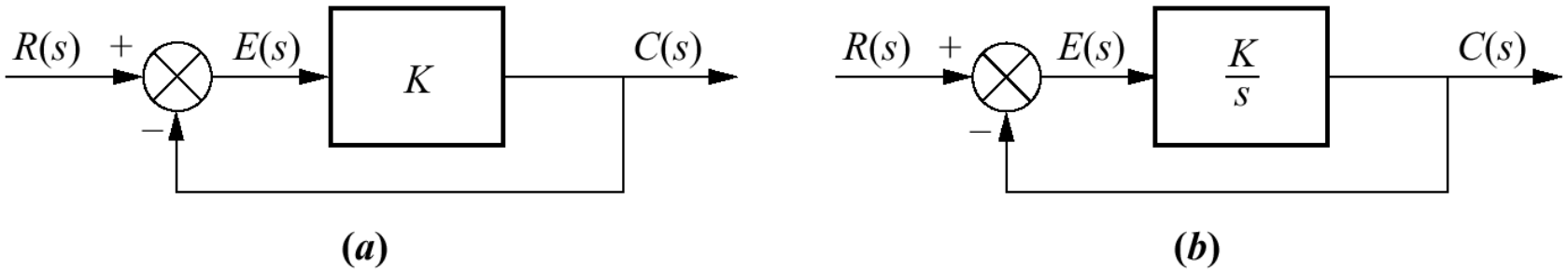


Figure 7.5
Feedback
control system for
Example 7.2

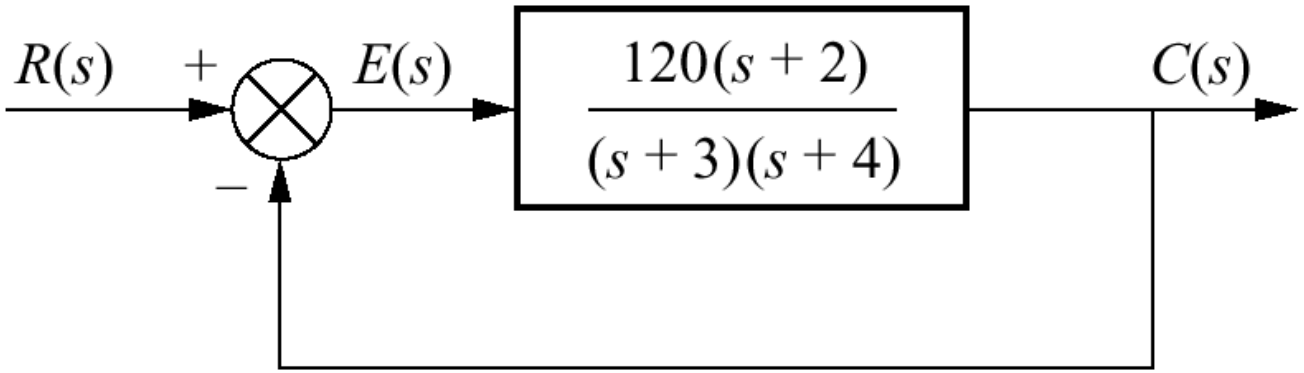


Figure 7.6
Feedback
control system for
Example 7.3

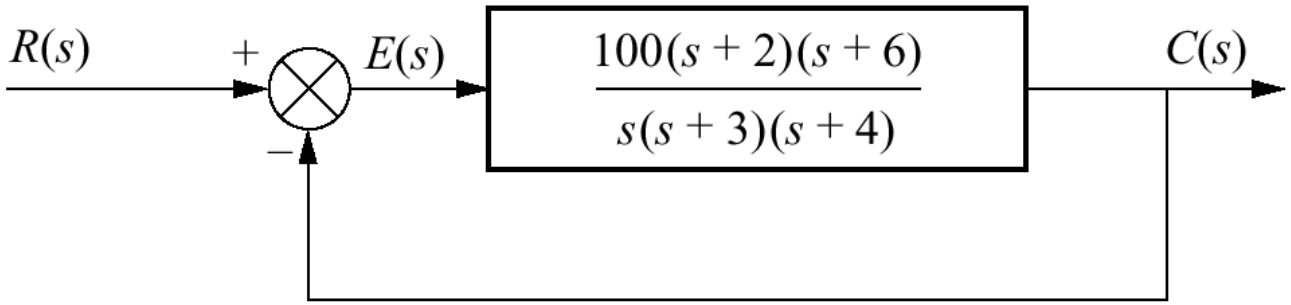


Figure 7.7 Feedback control systems for Example 7.4

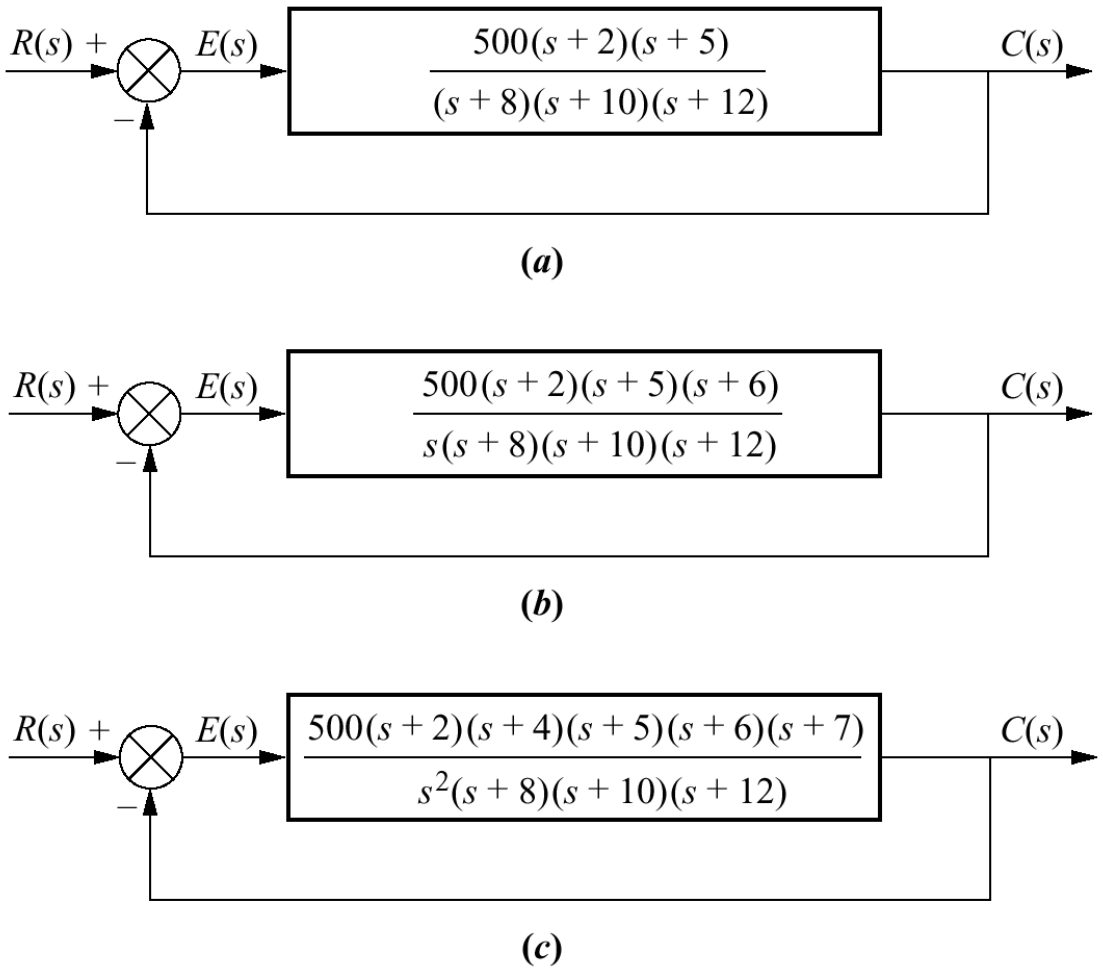


Figure 7.8
Feedback control system for defining system type

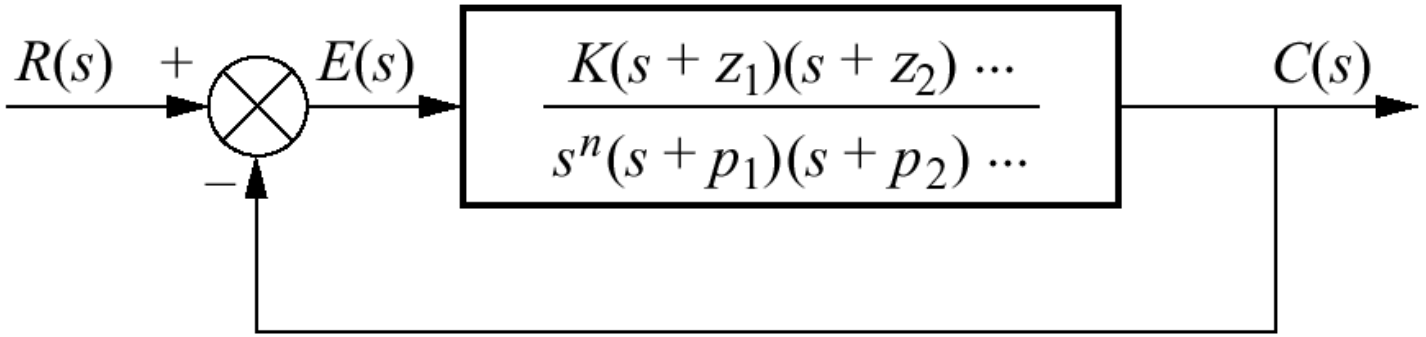


Table 7.2
Relationships between input, system type, static error constants, and steady-state errors

Input	Steady-state error formula	Type 0		Type 1		Type 2	
		Static error constant	Error	Static error constant	Error	Static error constant	Error
Step, $u(t)$	$\frac{1}{1+K_p}$	$K_p =$ Constant	$\frac{1}{1+K_p}$	$K_p = \infty$	0	$K_p = \infty$	0
Ramp, $tu(t)$	$\frac{1}{K_v}$	$K_v = 0$	∞	$K_v =$ Constant	$\frac{1}{K_v}$	$K_v = \infty$	0
Parabola, $\frac{1}{2}t^2u(t)$	$\frac{1}{K_a}$	$K_a = 0$	∞	$K_a = 0$	∞	$K_a =$ Constant	$\frac{1}{K_a}$

Figure 7.9
A robot used in the manufacturing of semiconductor random-access memories (RAMs) similar to those in personal computers. Steady-state error is an important design consideration for assembly-line robots.

Figure 7.10
Feedback
control system
for Example 7.6

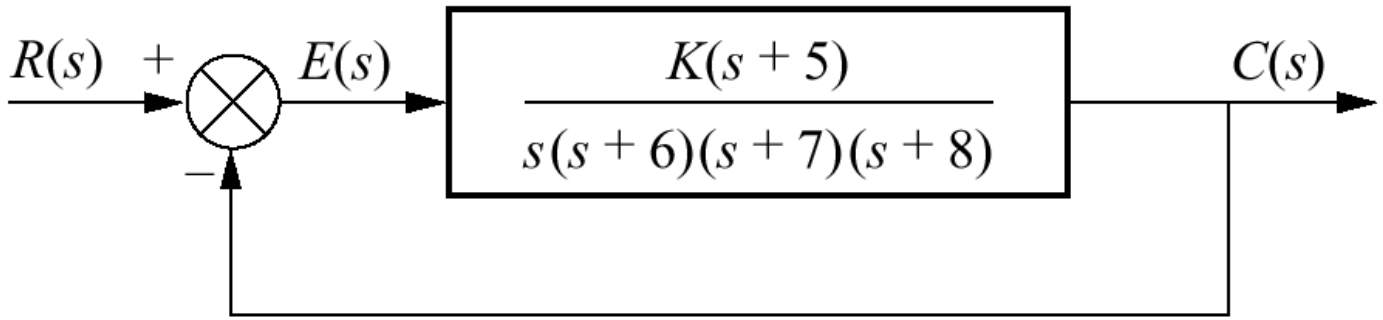


Figure 7.11
Feedback control system showing disturbance

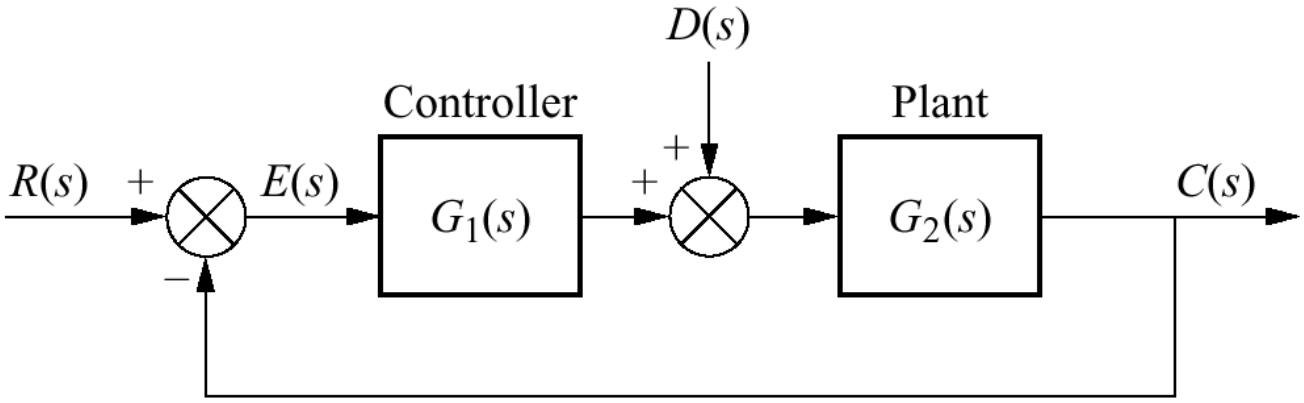


Figure 7.12
Figure 7.11 system rearranged to show disturbance as input and error as output, with R(s) = 0

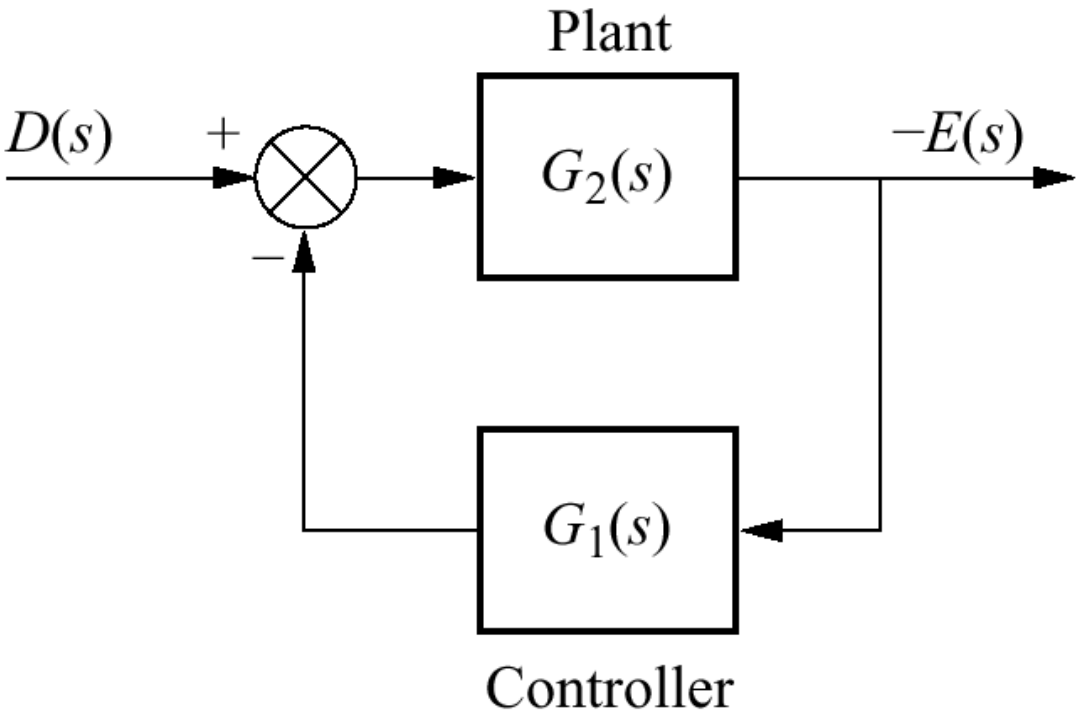


Figure 7.13
Feedback control system for
Example 7.7

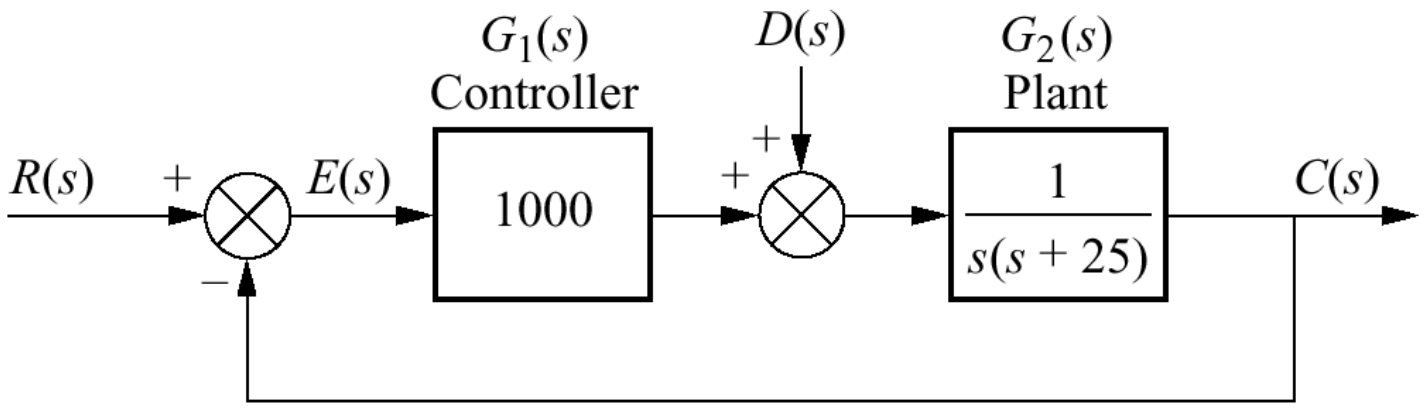


Figure 7.14
System for
Skill-Assessment
Exercise 7.4

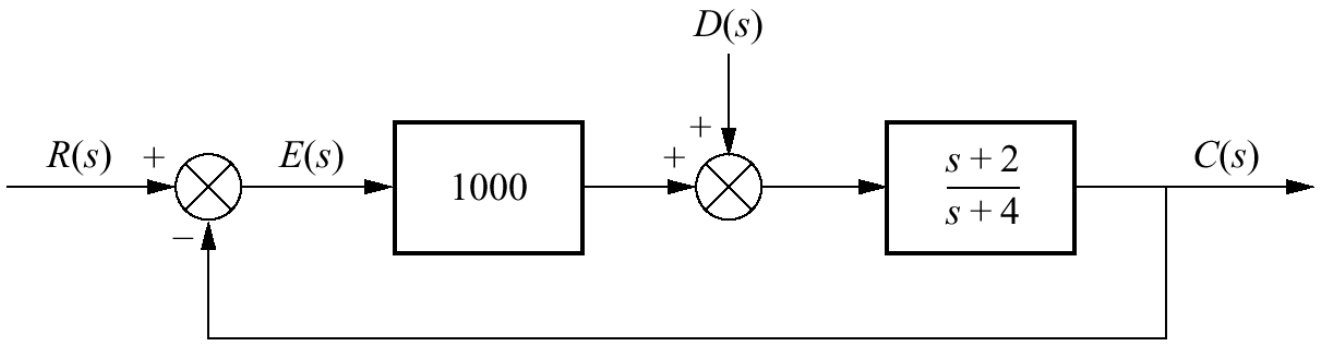


Figure 7.15
Forming an equivalent unity feedback system from a general nonunity feedback system

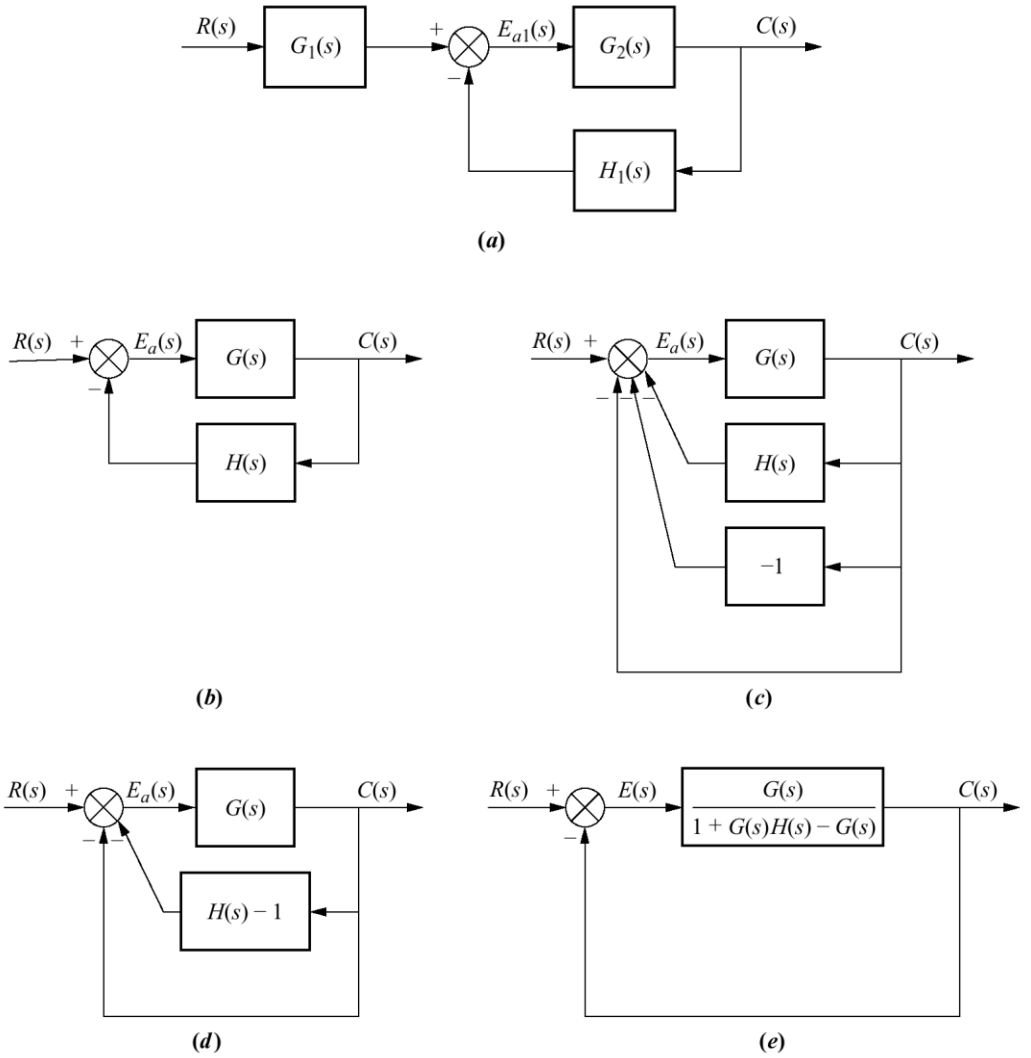


Figure 7.16
Nonunity feedback control system for Example 7.8

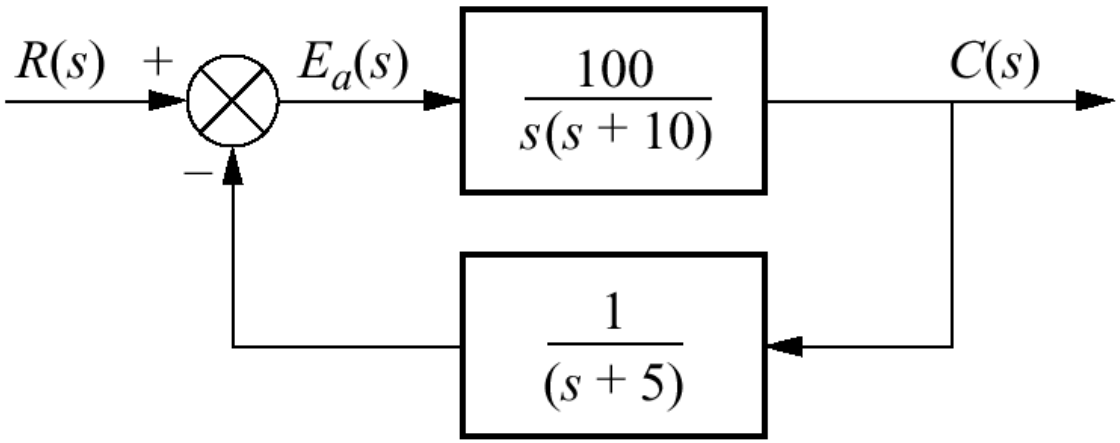


Figure 7.17
Nonunity feedback control system with disturbance

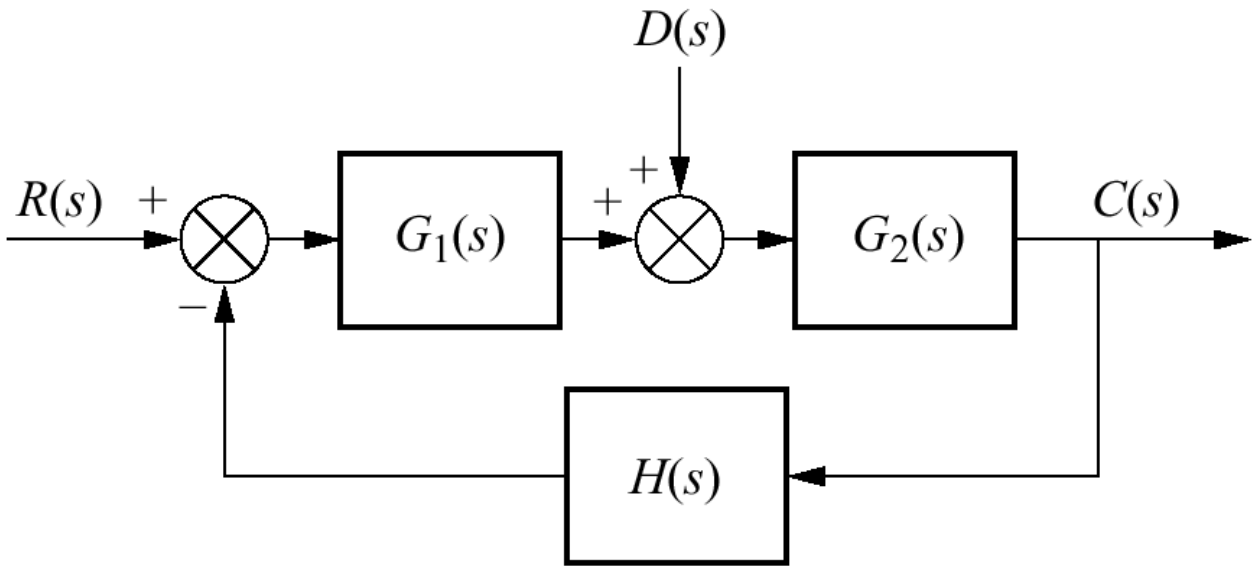


Figure 7.18
Nonunity feedback system for Skill-Assessment Exercise 7.5

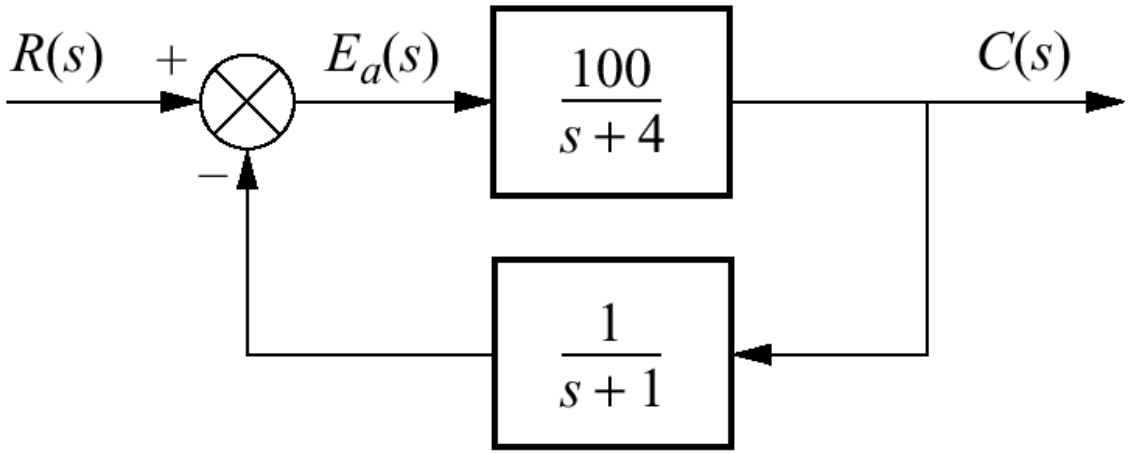


Figure 7.19
Feedback control system for Examples 7.10 and 7.11

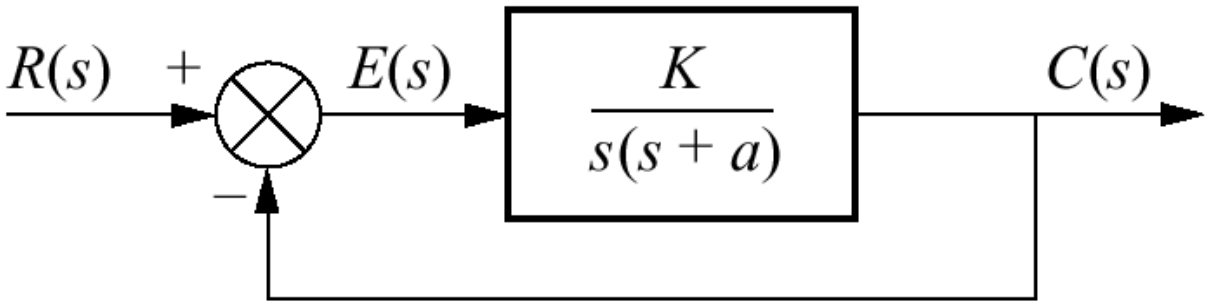


Figure 7.20
Feedback
control system
for Example 7.12

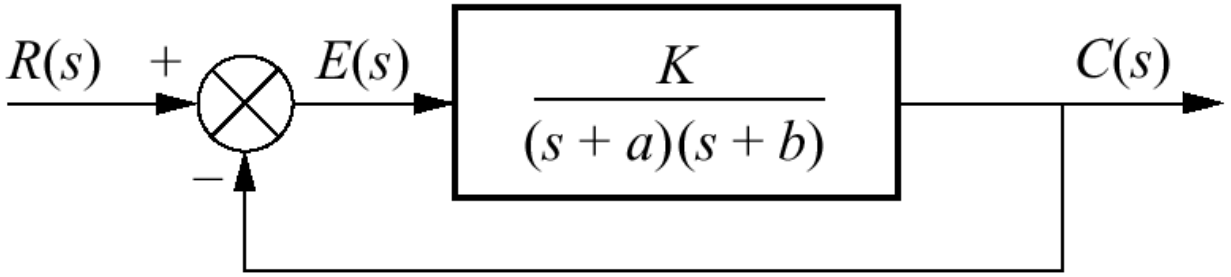


Figure 7.21
System for
Skill-Assessment
Exercise 7.6

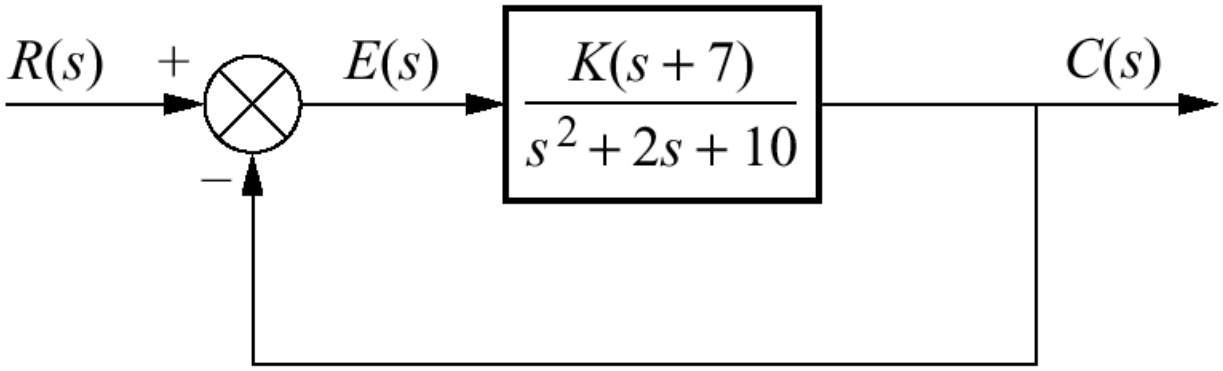


Figure 7.22
Video laser disc recording:
control system for focusing write beam

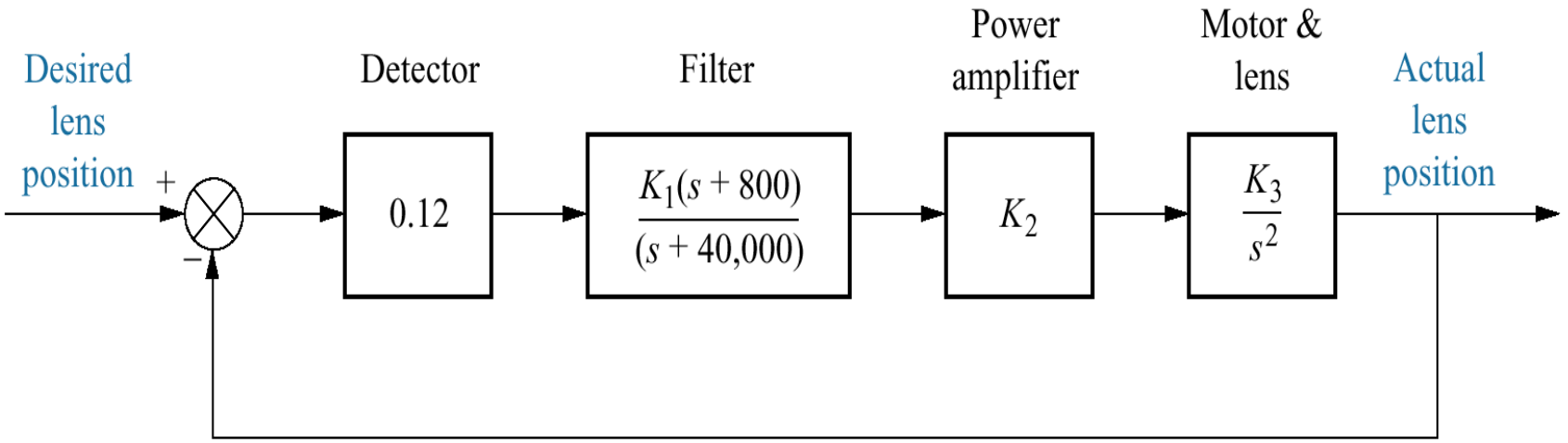


Figure 7.23
Video disc laser recording:
a. focus detector optics;
b. linearized transfer function for focus detector

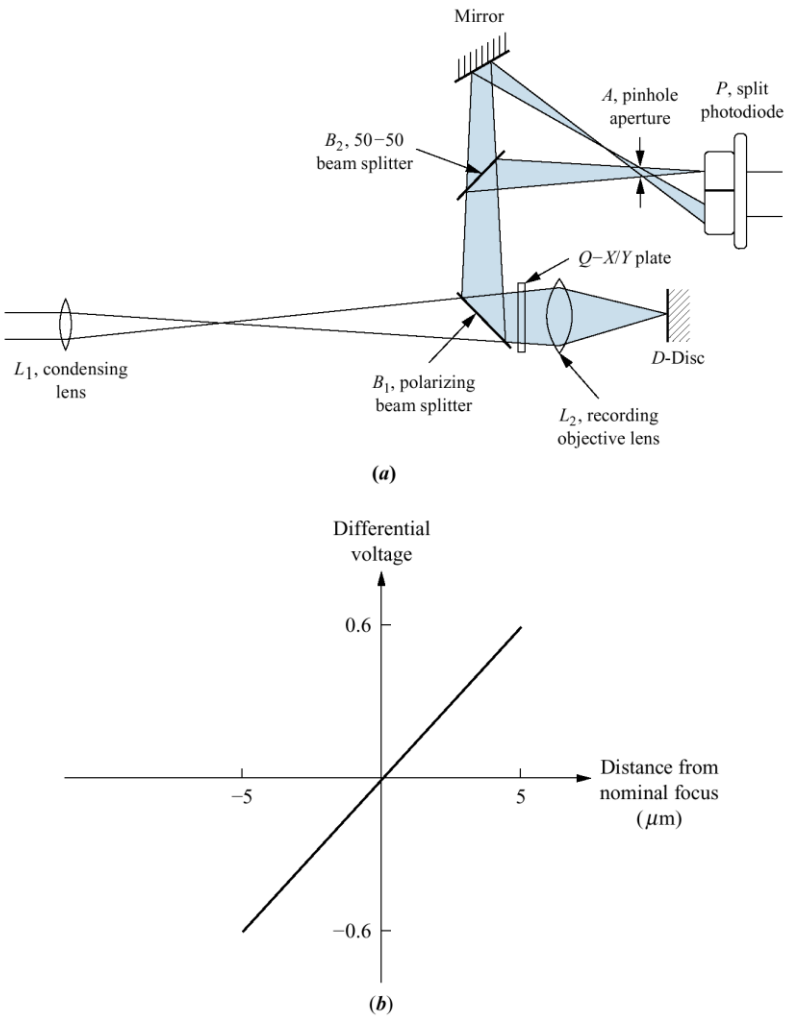
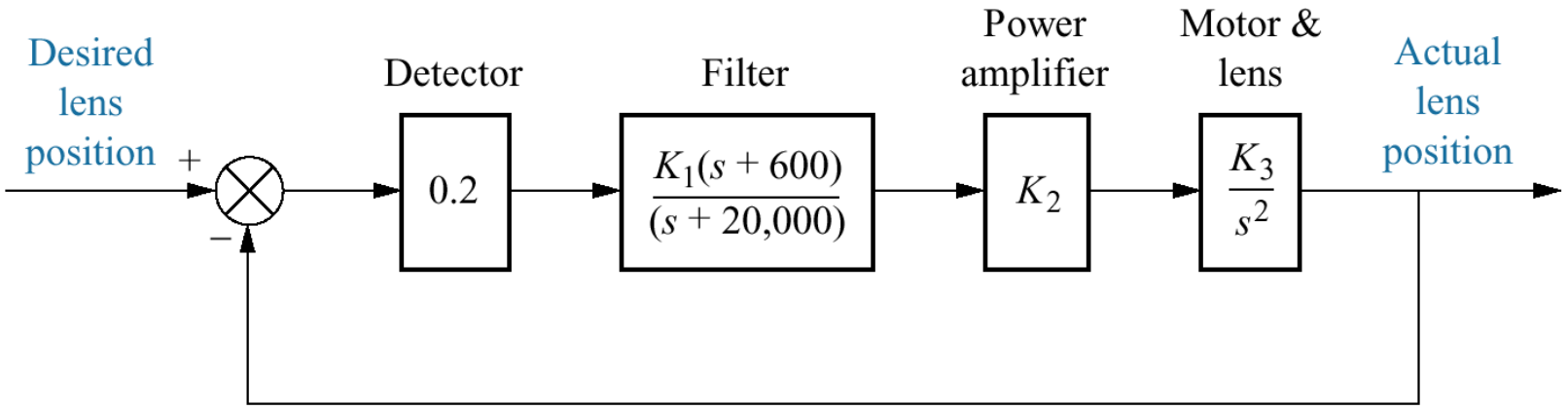


Figure 7.24
Video laser disc recording focusing system



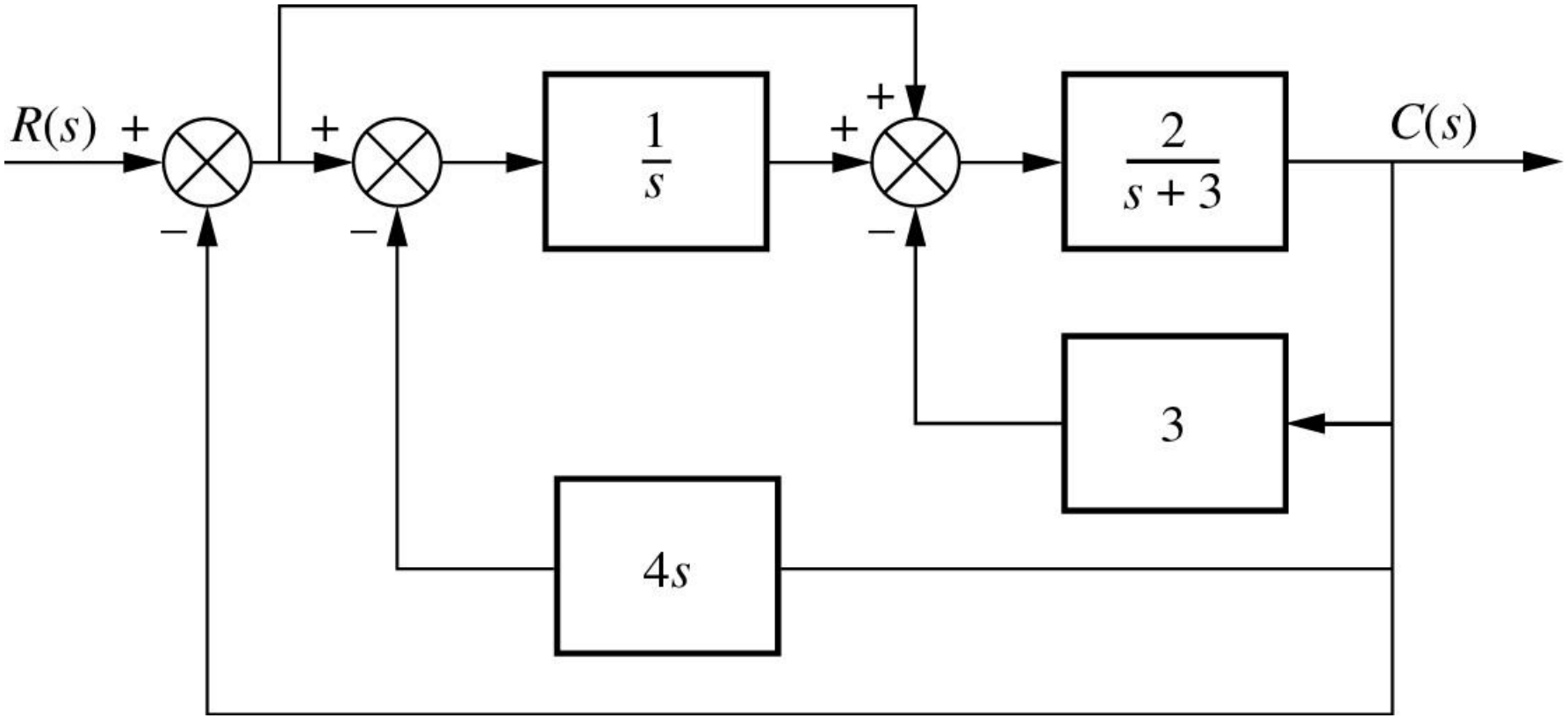


Figure P7-2 (p. 405)

Figure P7.3

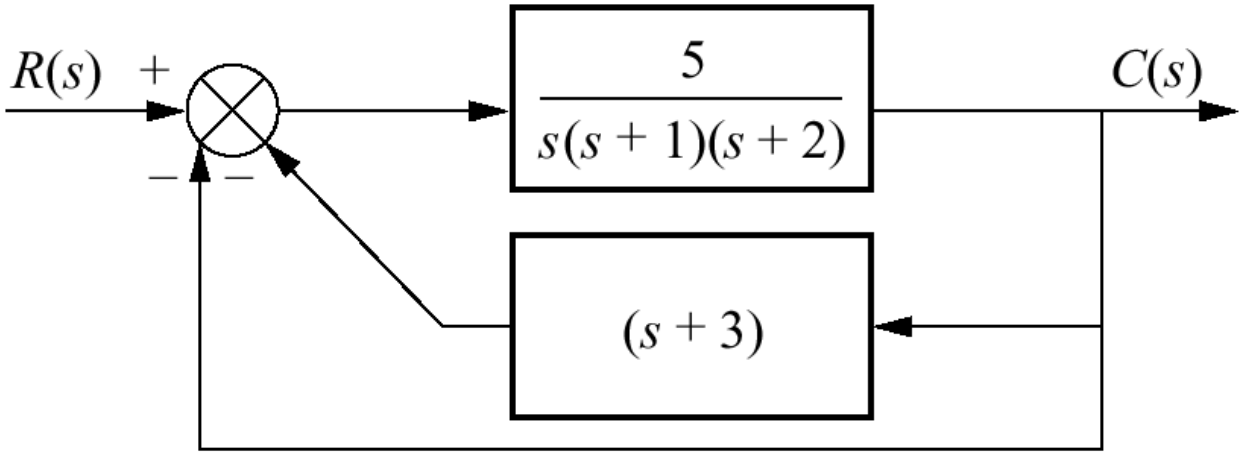
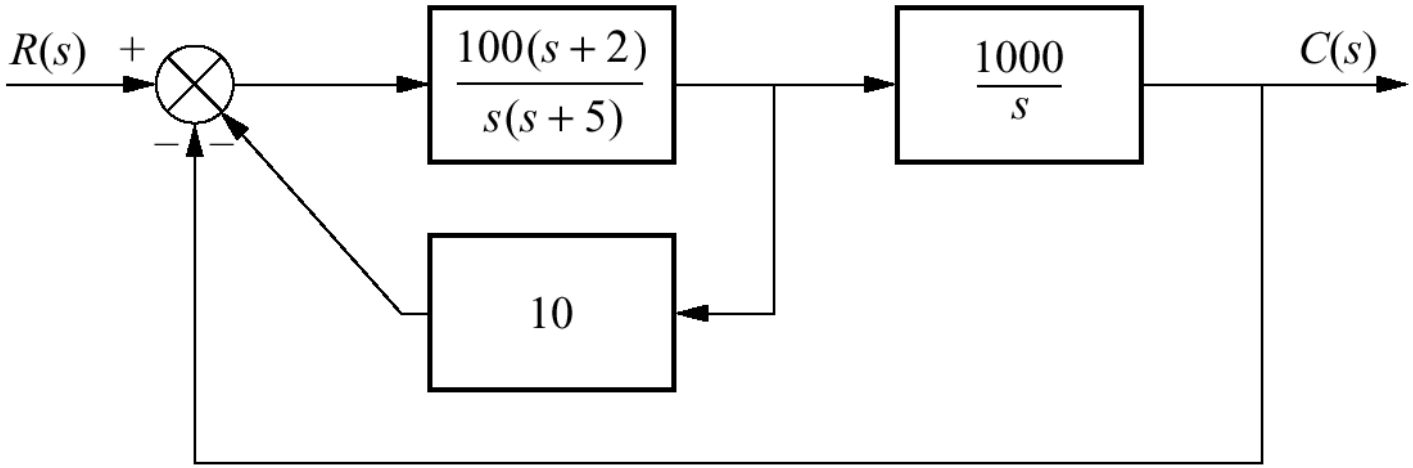


Figure P7.4



Input \ Type	0	1	2
Step			
Ramp			
Parabola			

Table P7.1

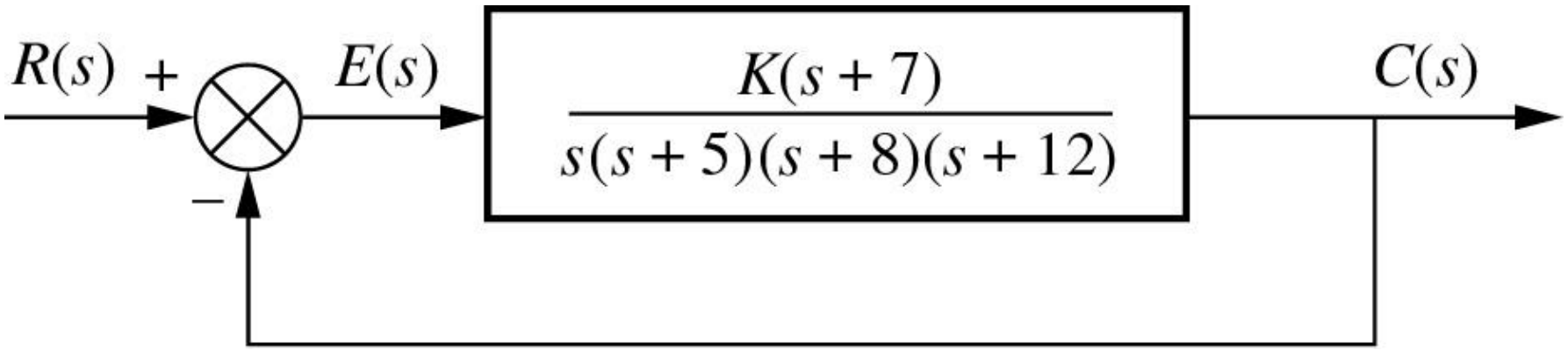


Figure P7-5 (p. 408)

Figure P7.6

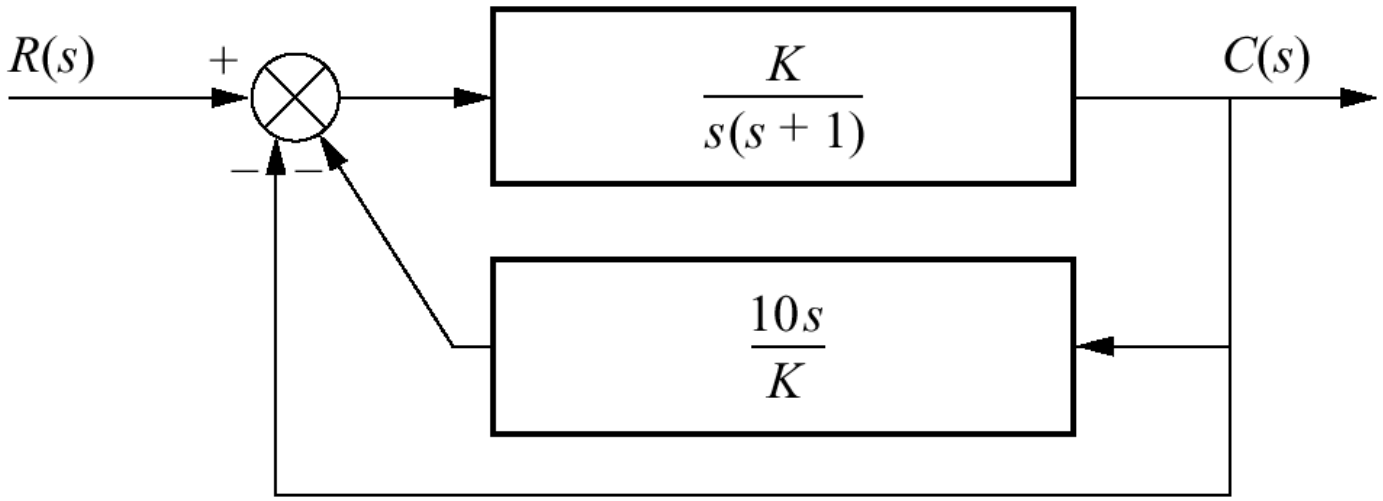


Figure P7.7

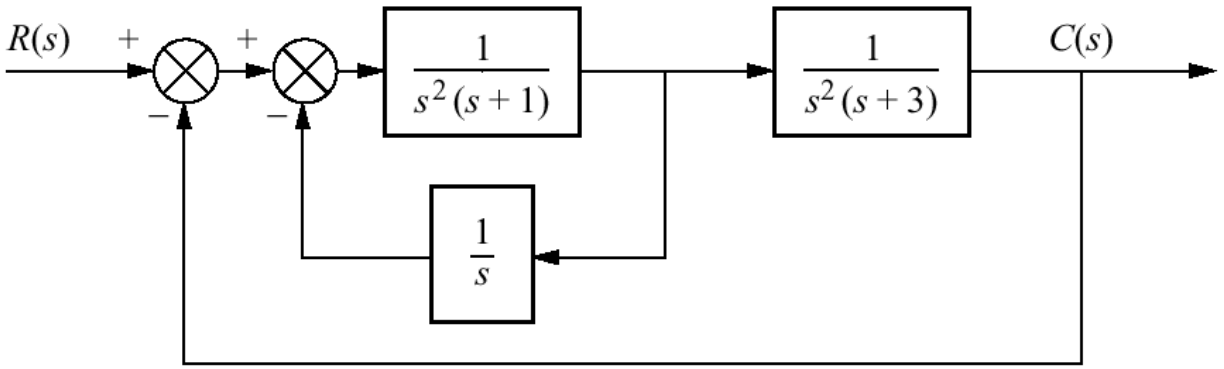


Figure P7.8

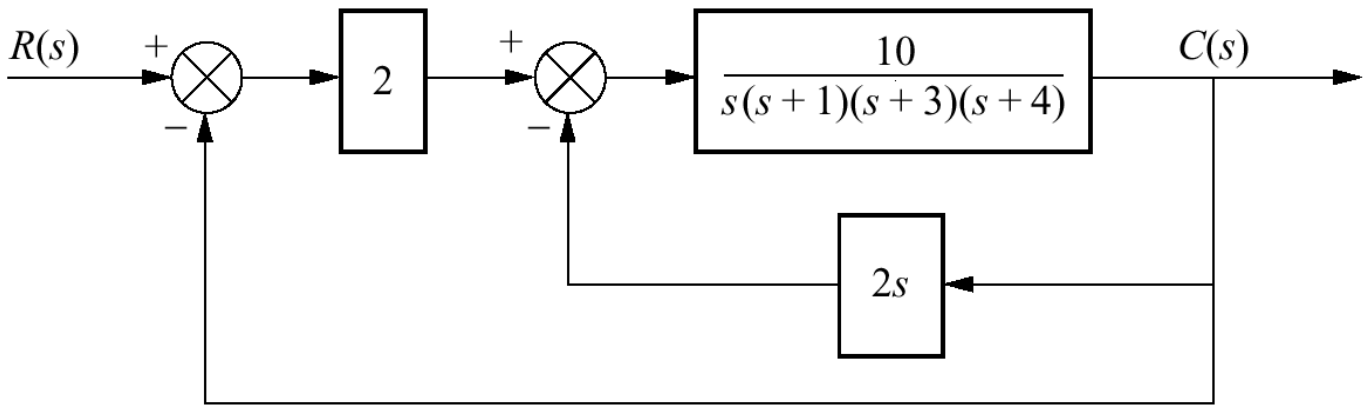


Figure P7.9

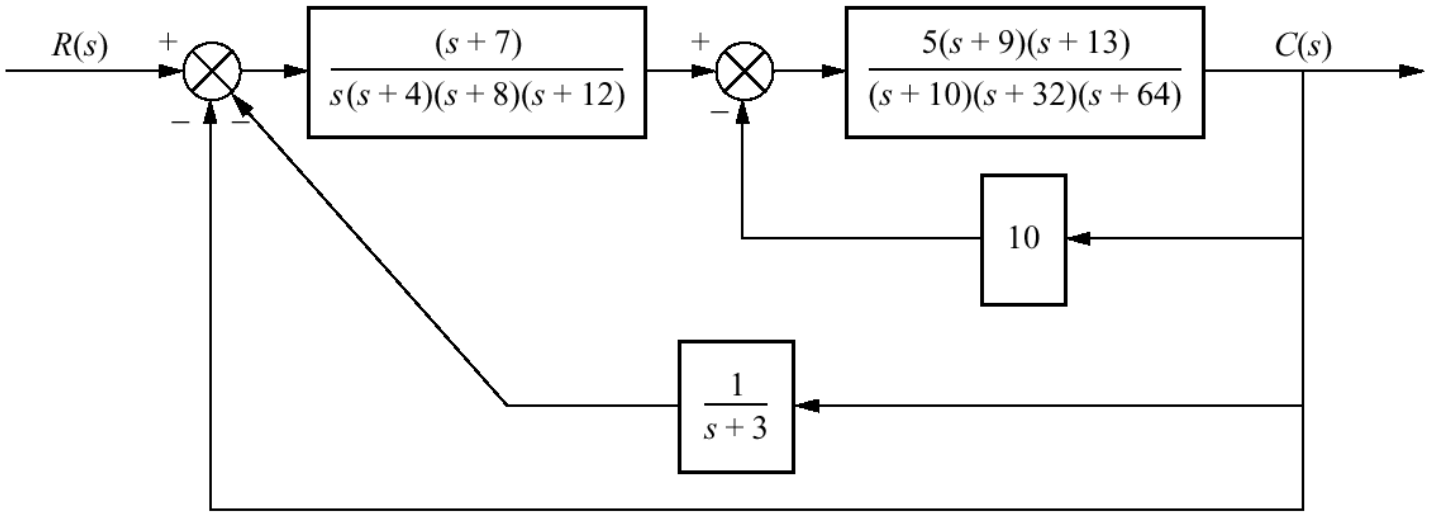


Figure P7.10

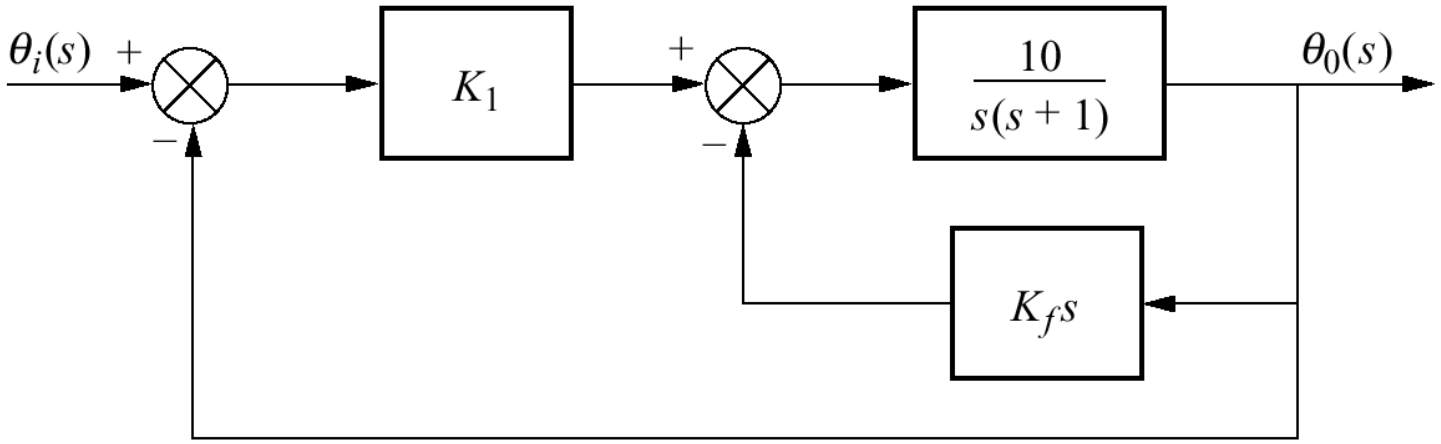


Figure P7.11

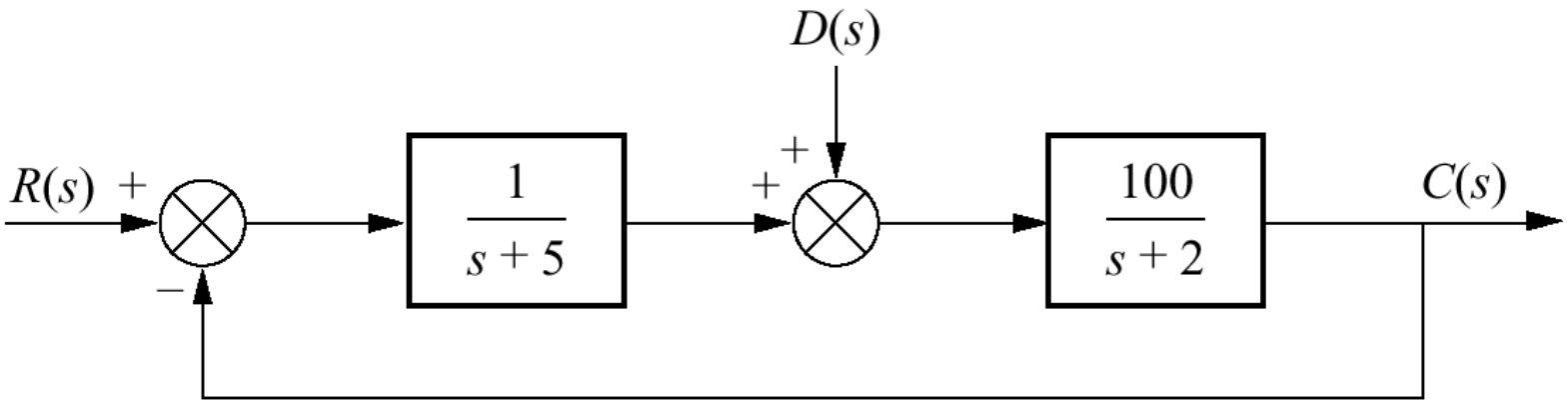


Figure P7.12

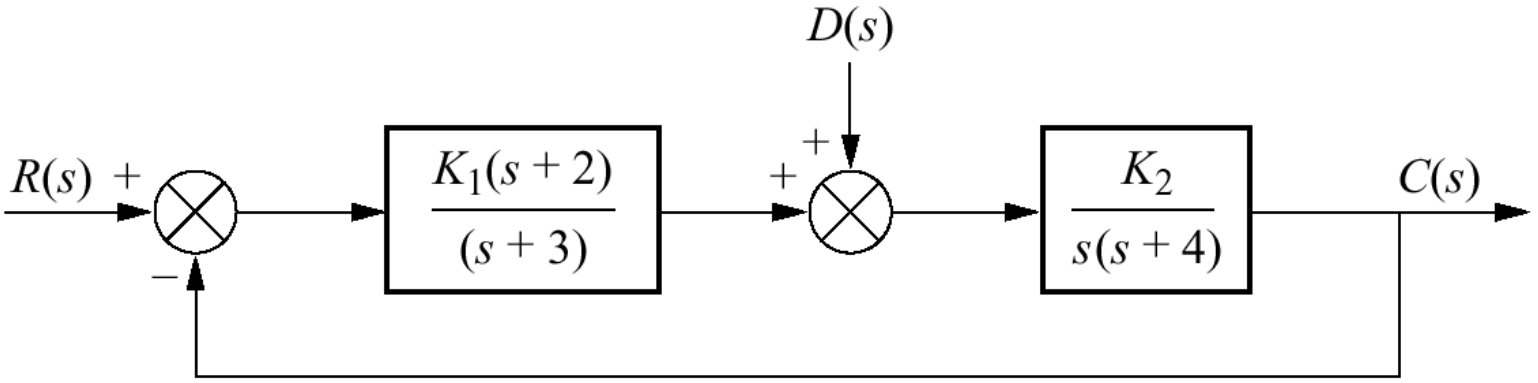
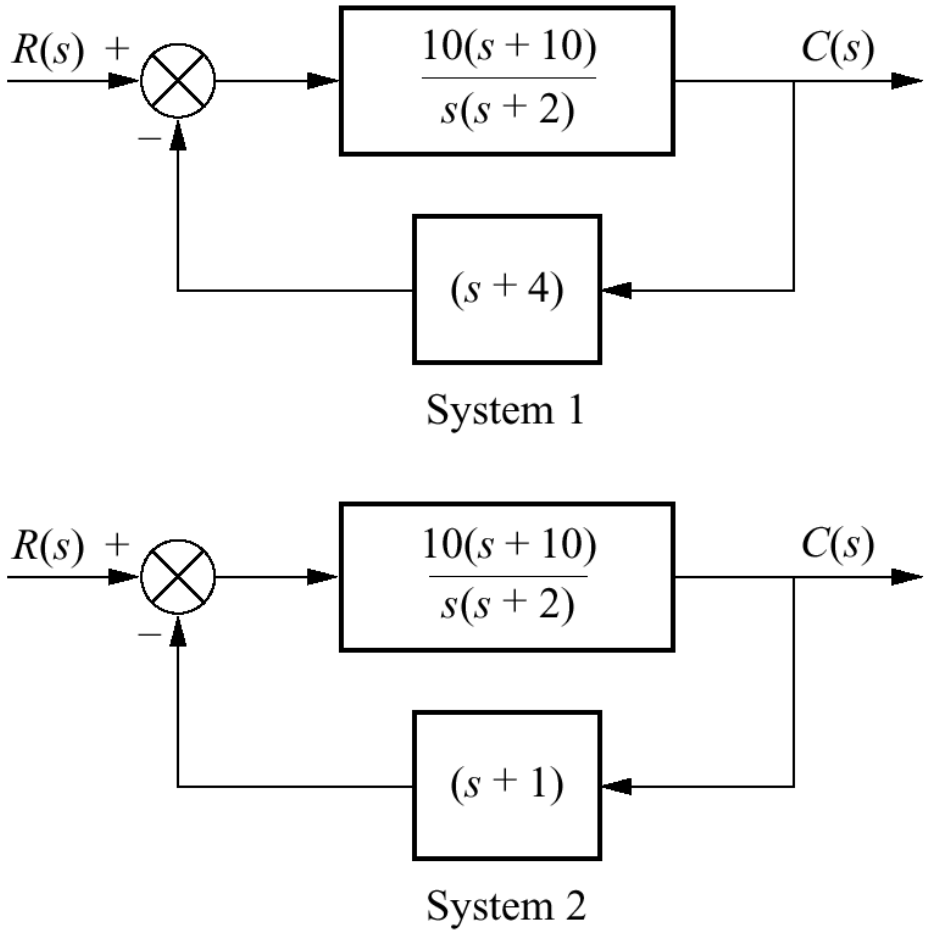
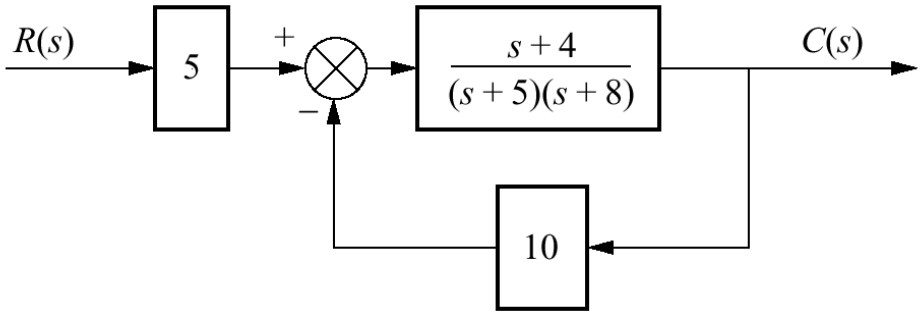
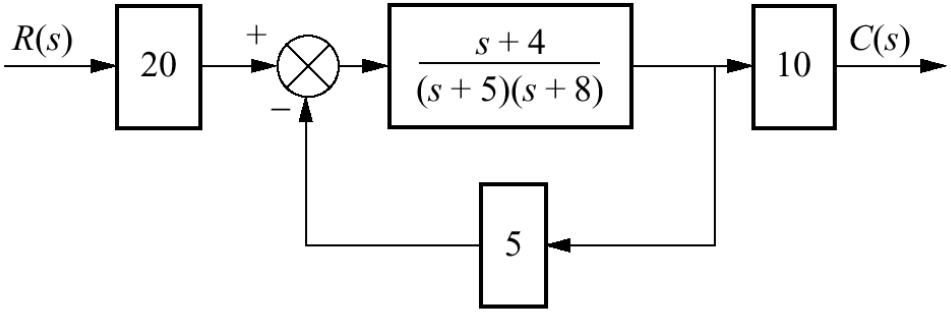


Figure P7.13
Closed-loop systems with nonunity feedback





System 1



System 2

Figure P7.14

Figure P7.15

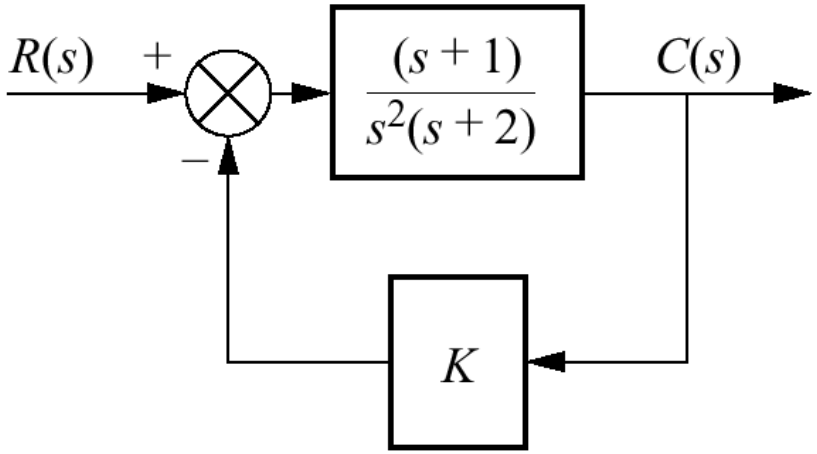


Figure P7.16

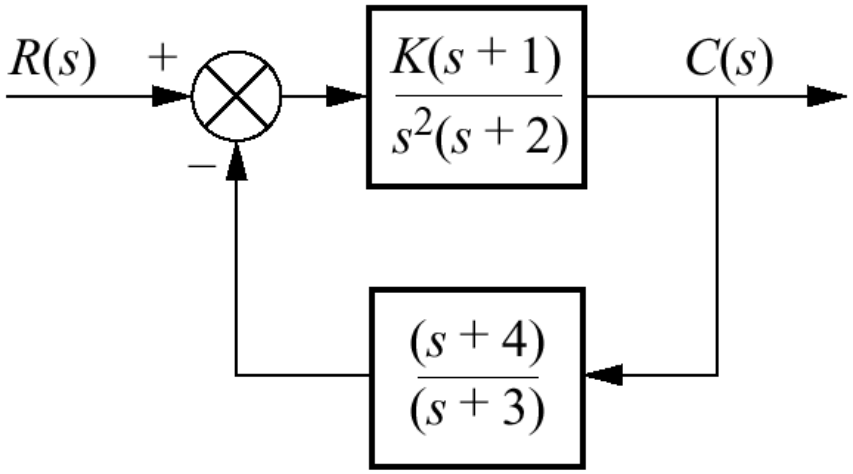


Figure P7.17

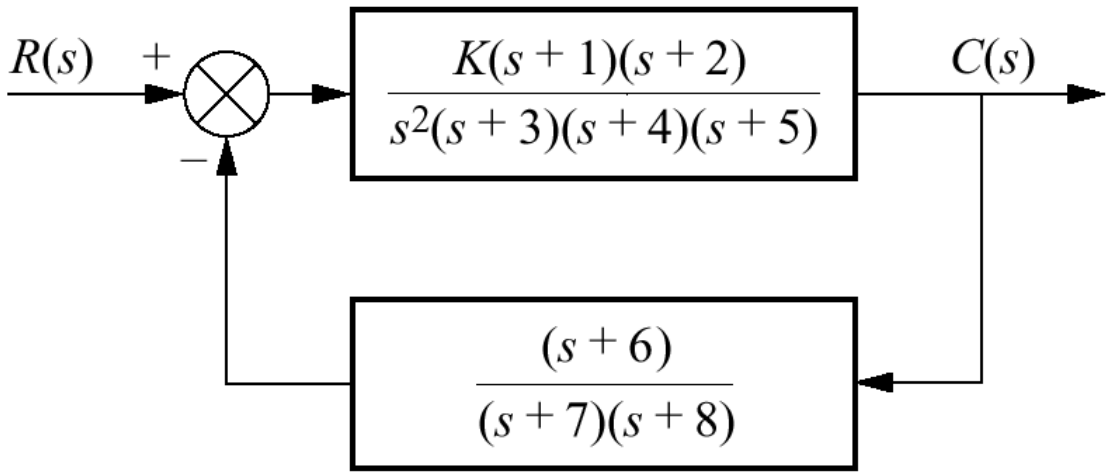


Figure P7.18
System with input and disturbance

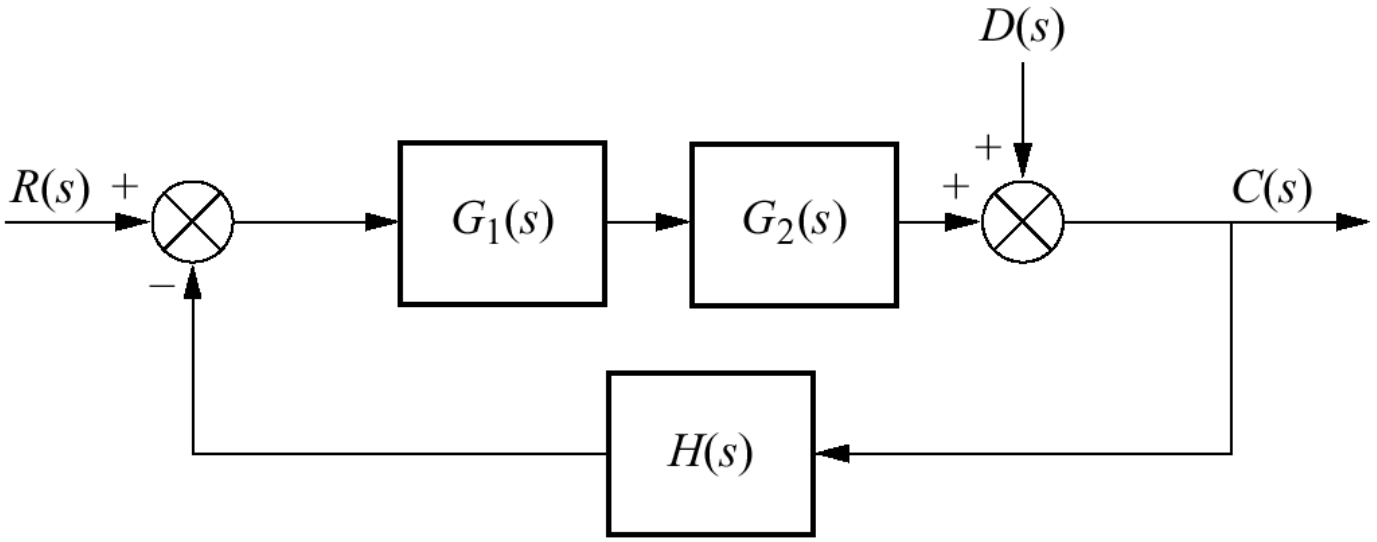


Figure P7.19

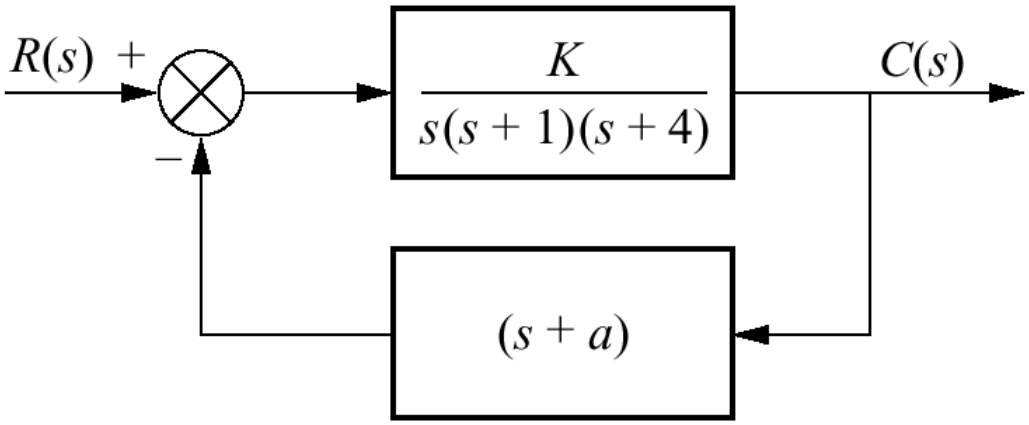


Figure P7.20
System with input and disturbance

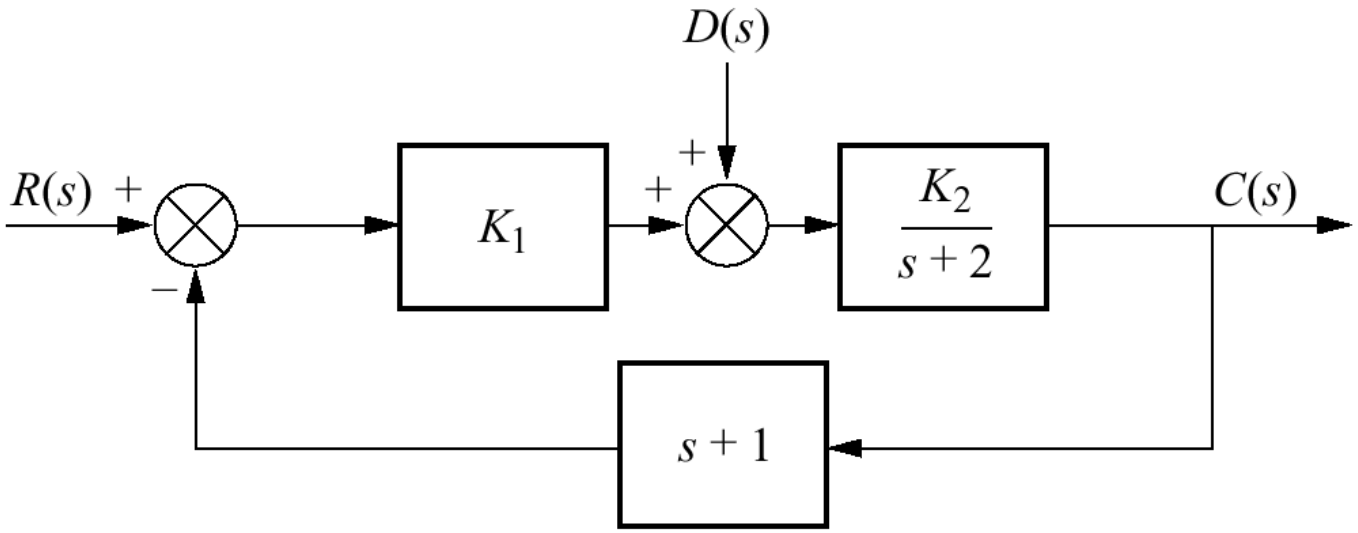


Figure P7.21
Automobile guidance system
a. displacement control system;
b. velocity control loop

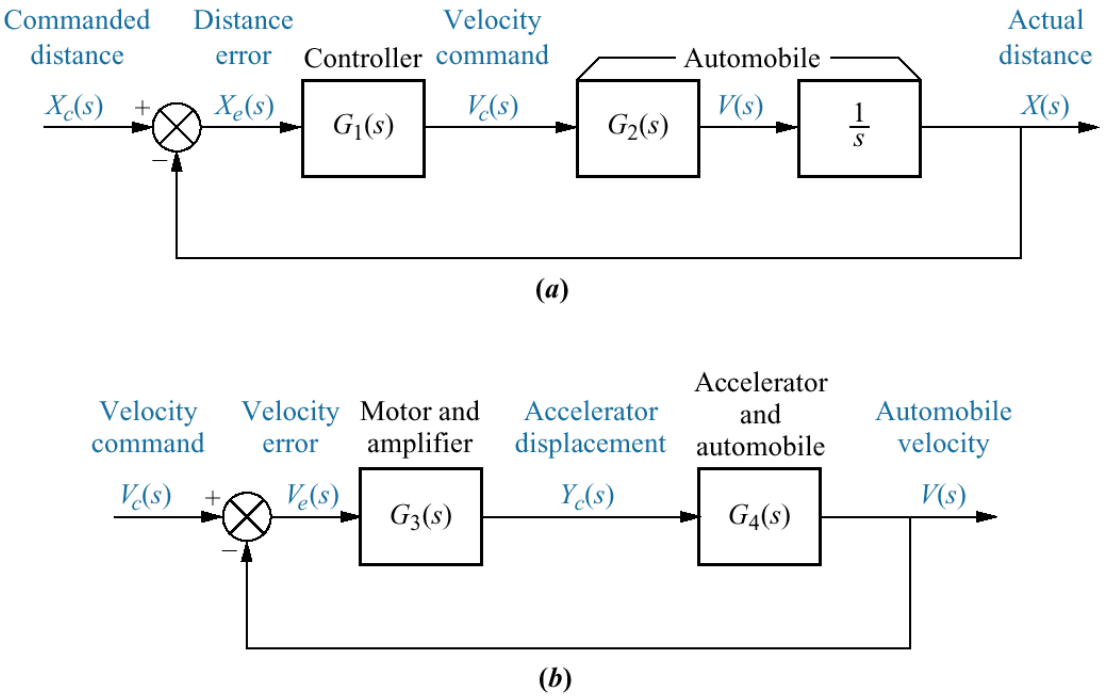


Figure P7.22
Block diagram of a paramagnetic oxygen analyzer

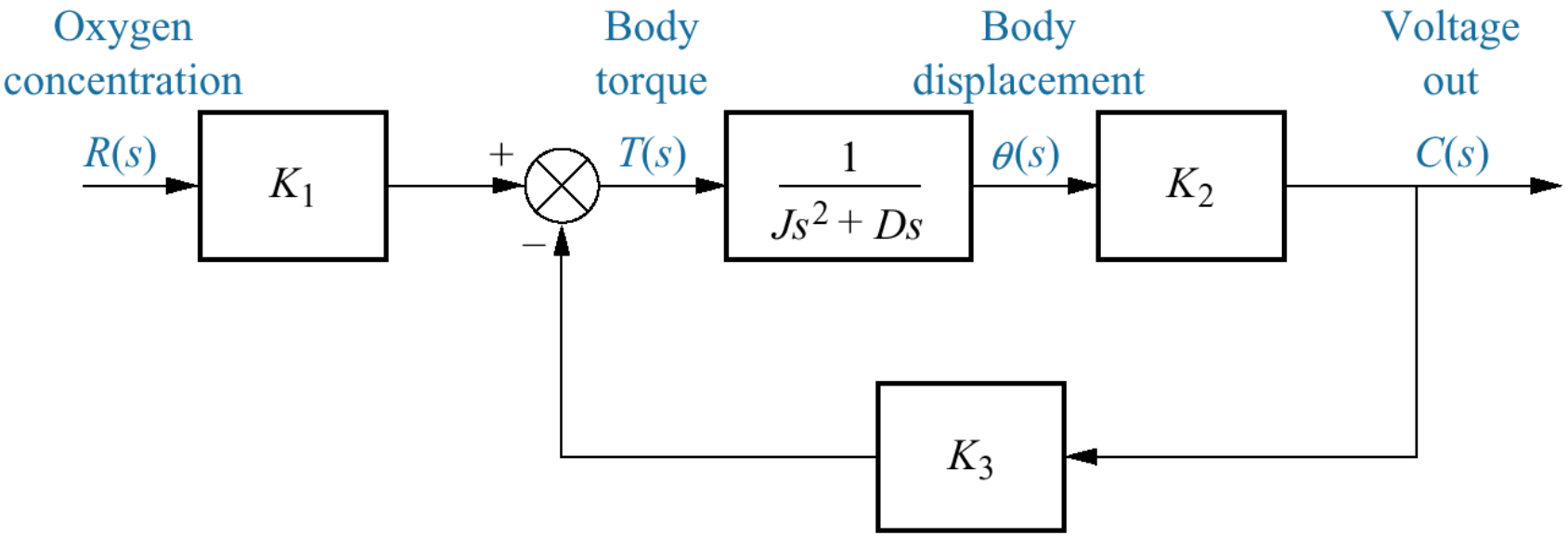


Figure P7.23
Space station Freedom:
a. configuration
(*figure continues)*

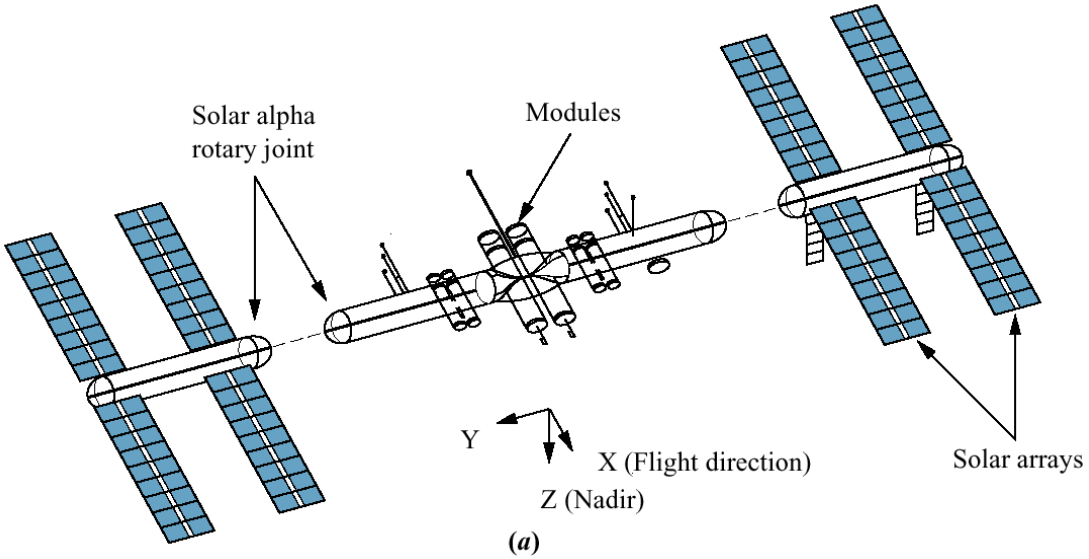
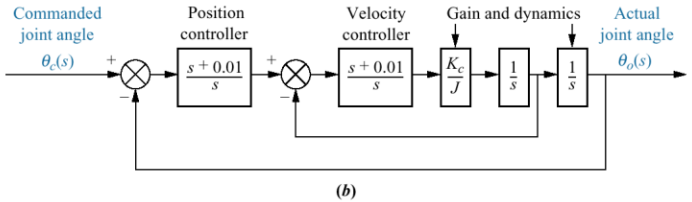


Figure P7.23
(*continued*)
b. simplified block diagram
c. alpha joint drive train and control system



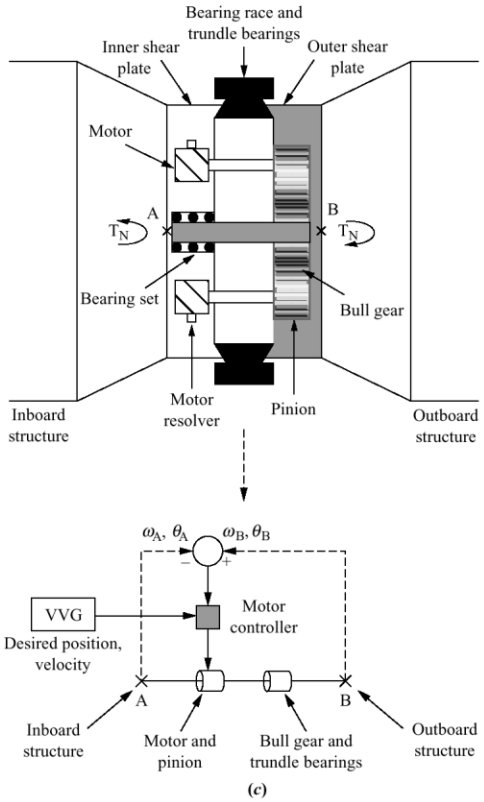


Figure P7.24
Position control system

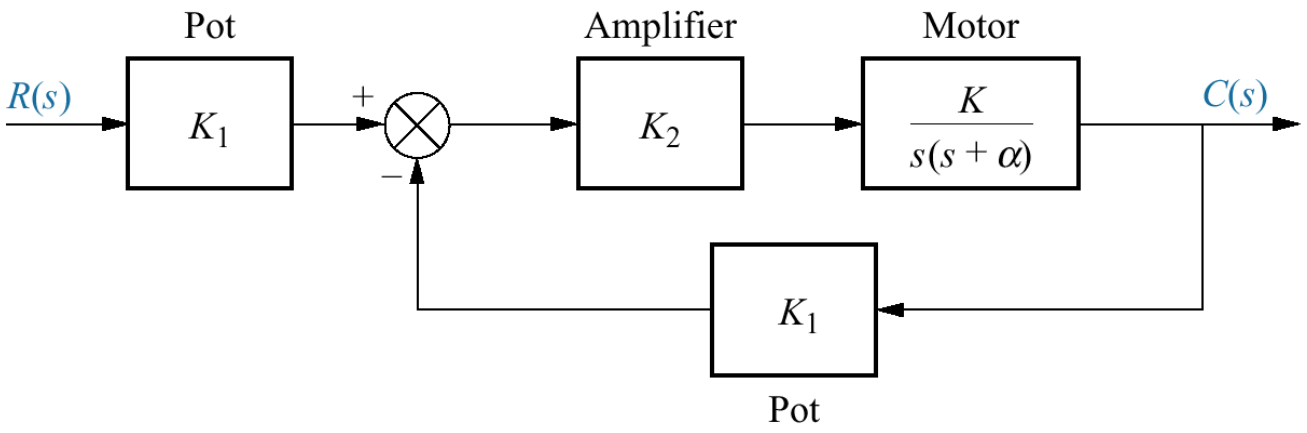
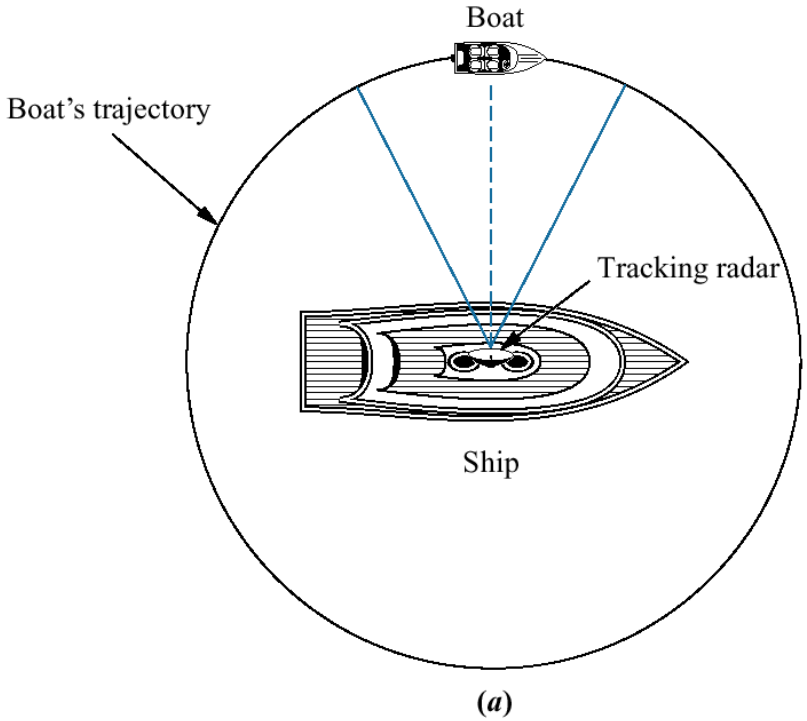


Figure P7.25
Boat tracked by ship's radar:
a. physical arrangement;
b. block diagram of tracking system



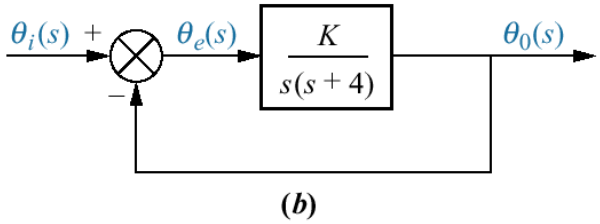


Figure P7.26
Simplified block diagram of a pilot in a loop

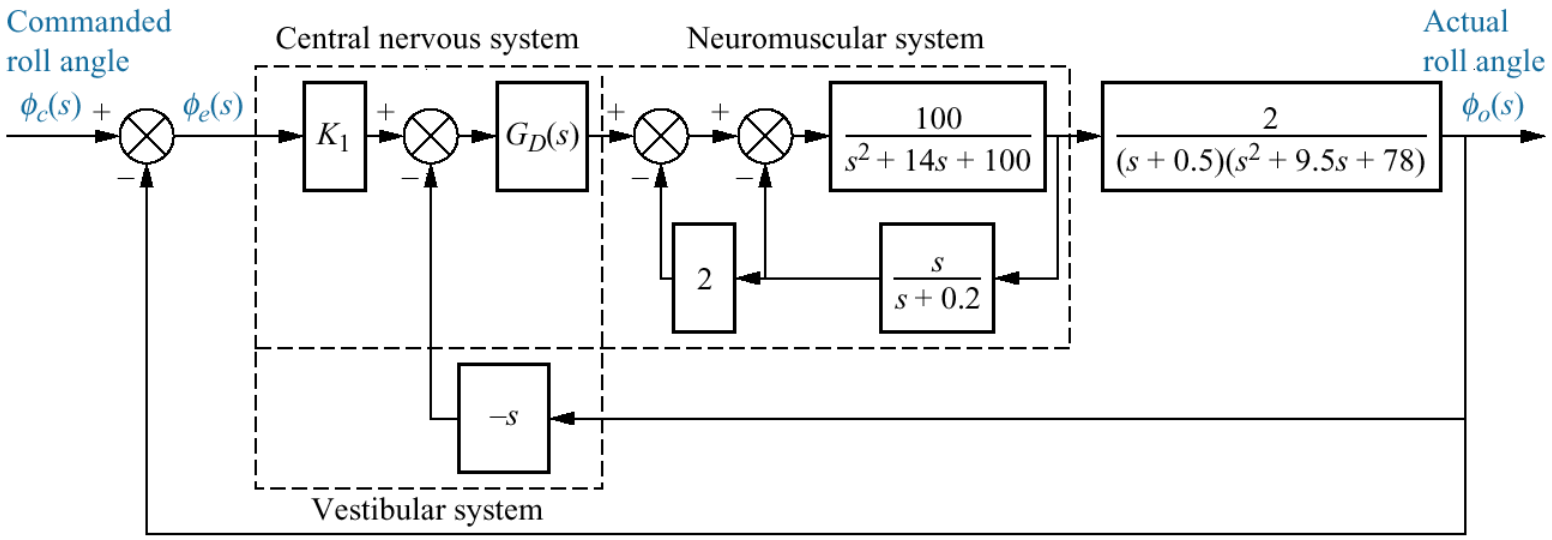


Figure P7.27
a. Force control mechanical loop under contact motion (©1996 IEEE);
b. block diagram (©1996 IEEE)