Chapter 5

Reduction of Multiple Subsystems

Figure 5.1
The space shuttle consists of multiple subsystems. Can you identify those that are control systems, or parts of control systems?

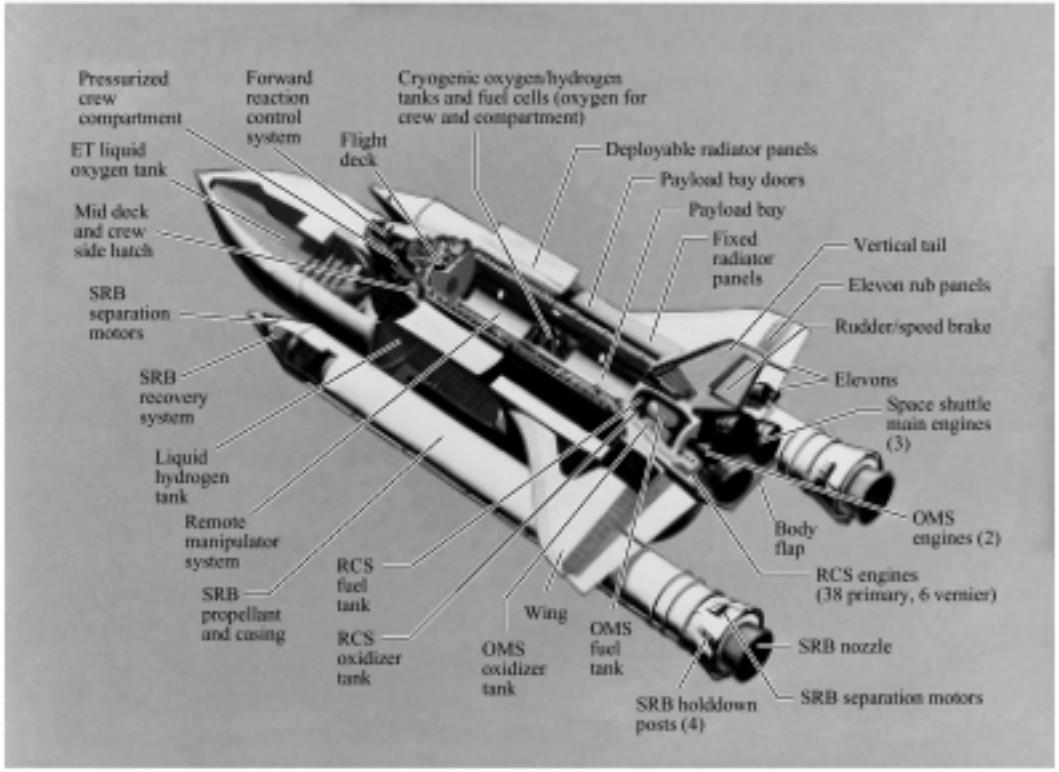


Figure 5.2
Components of a block diagram for a linear, time-invariant system

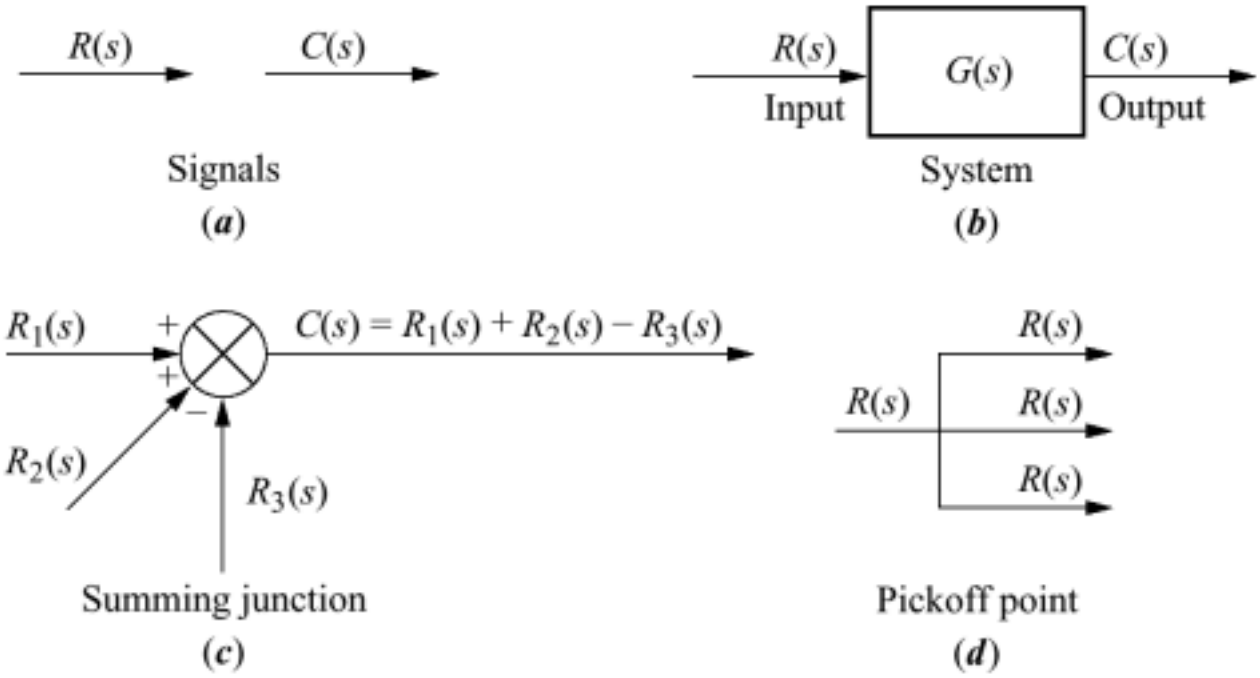


Figure 5.3
a. Cascaded subsystems;
b. equivalent transfer function

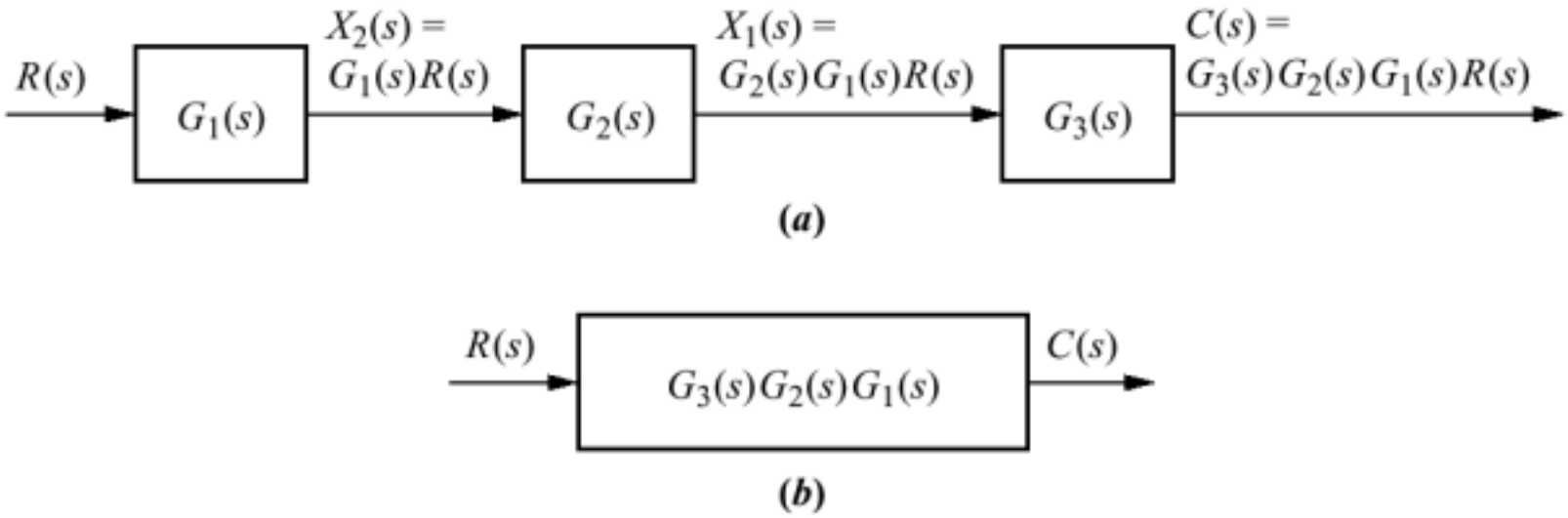


Figure 5.4
Loading in cascaded systems

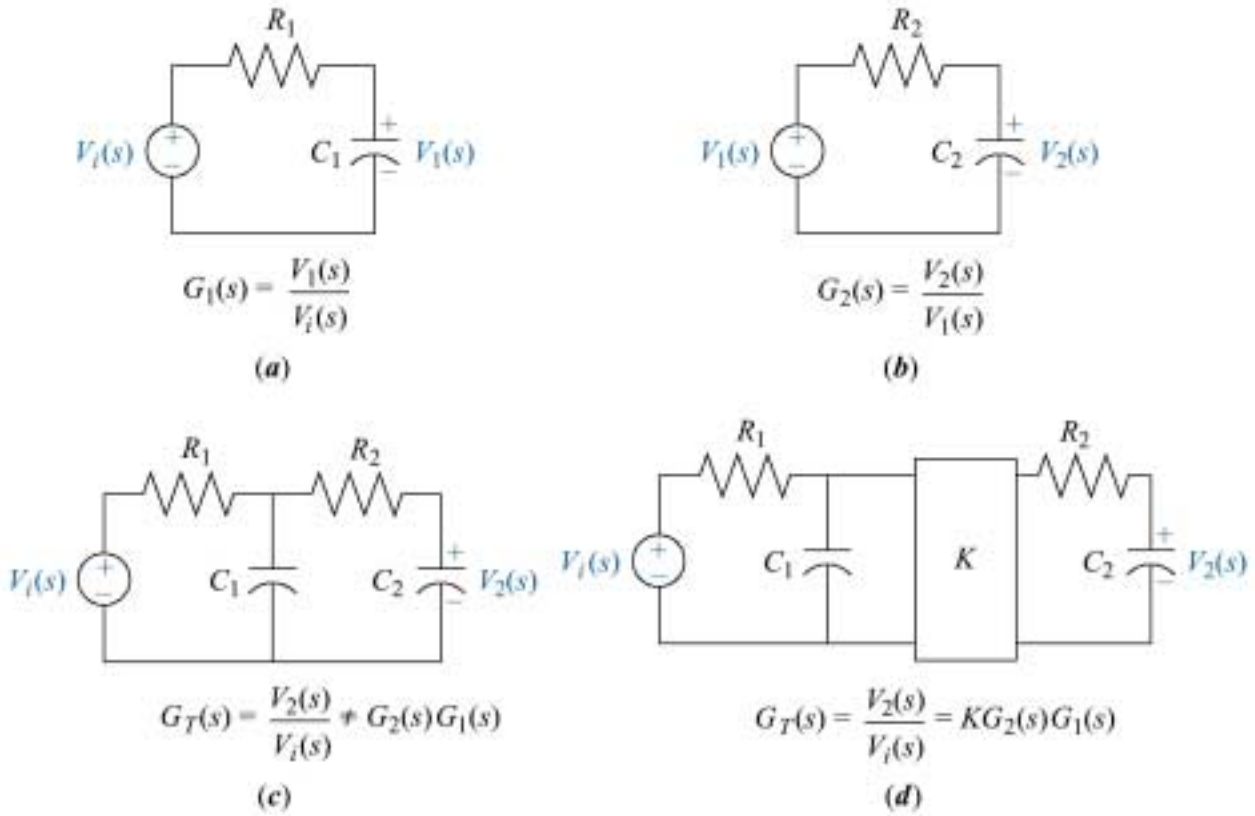


Figure 5.5
a. Parallel subsystems;
b. equivalent transfer function

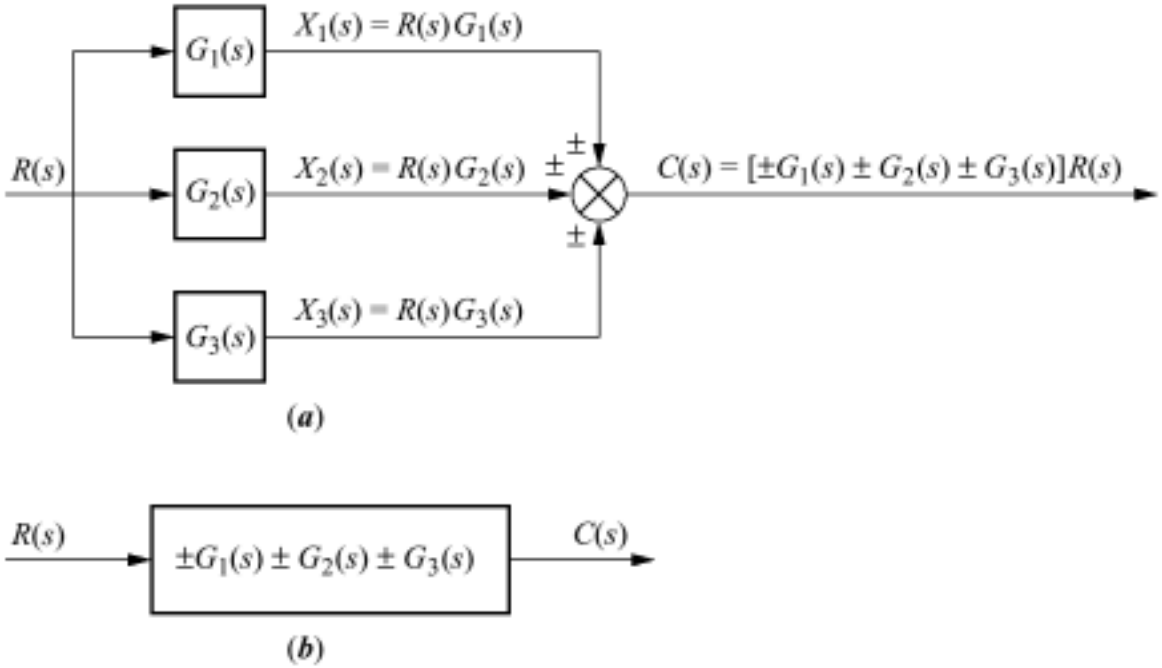


Figure 5.6
a. Feedback control system;
b. simplified model;
c. equivalent transfer function

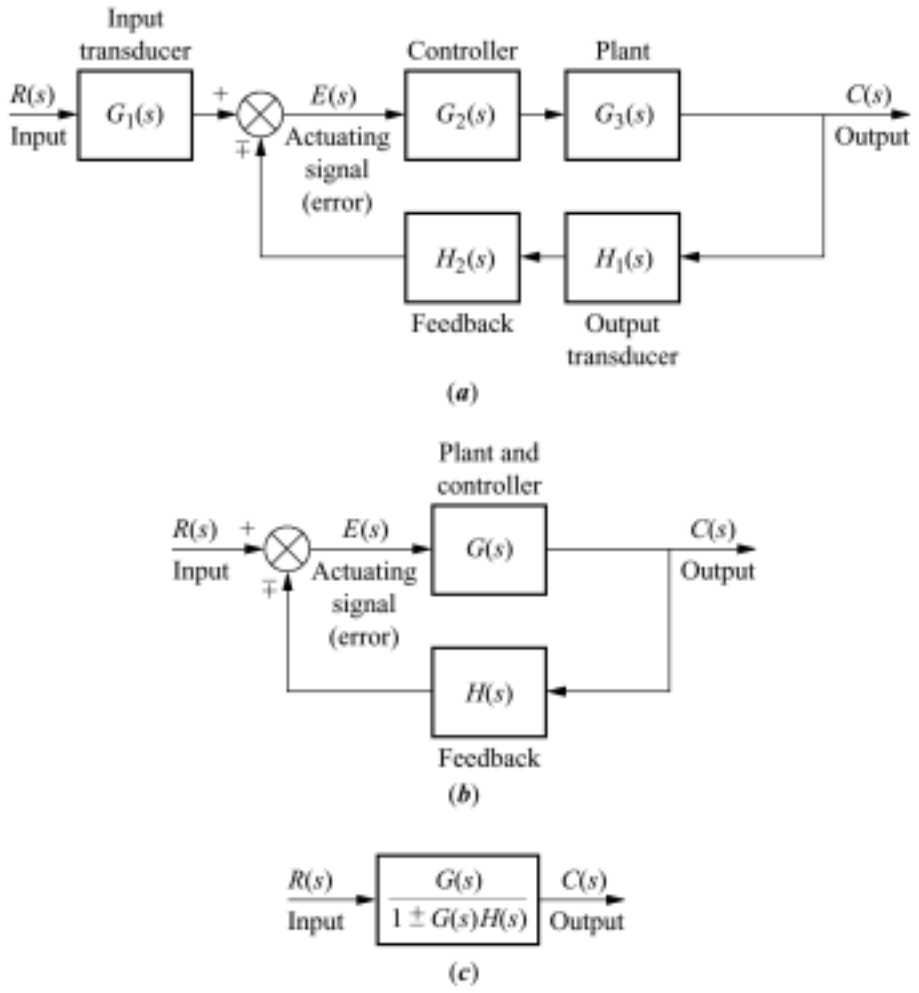


Figure 5.7
Block diagram algebra for summing junctions—equivalent forms for moving a block
a. to the left past a summing junction;
b. to the right past a summing junction

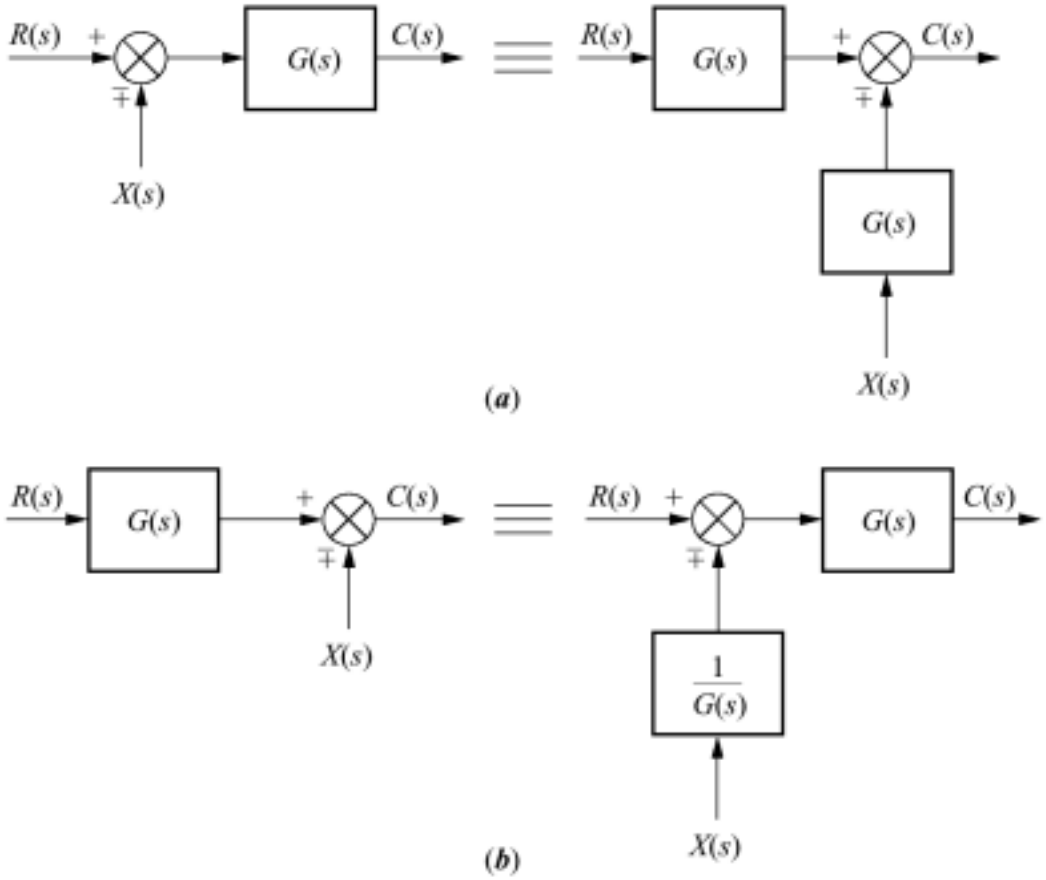


Figure 5.8
Block diagram algebra for pickoff points—equivalent forms for moving a block
a. to the left past a pickoff point;
b. to the right past a pickoff point

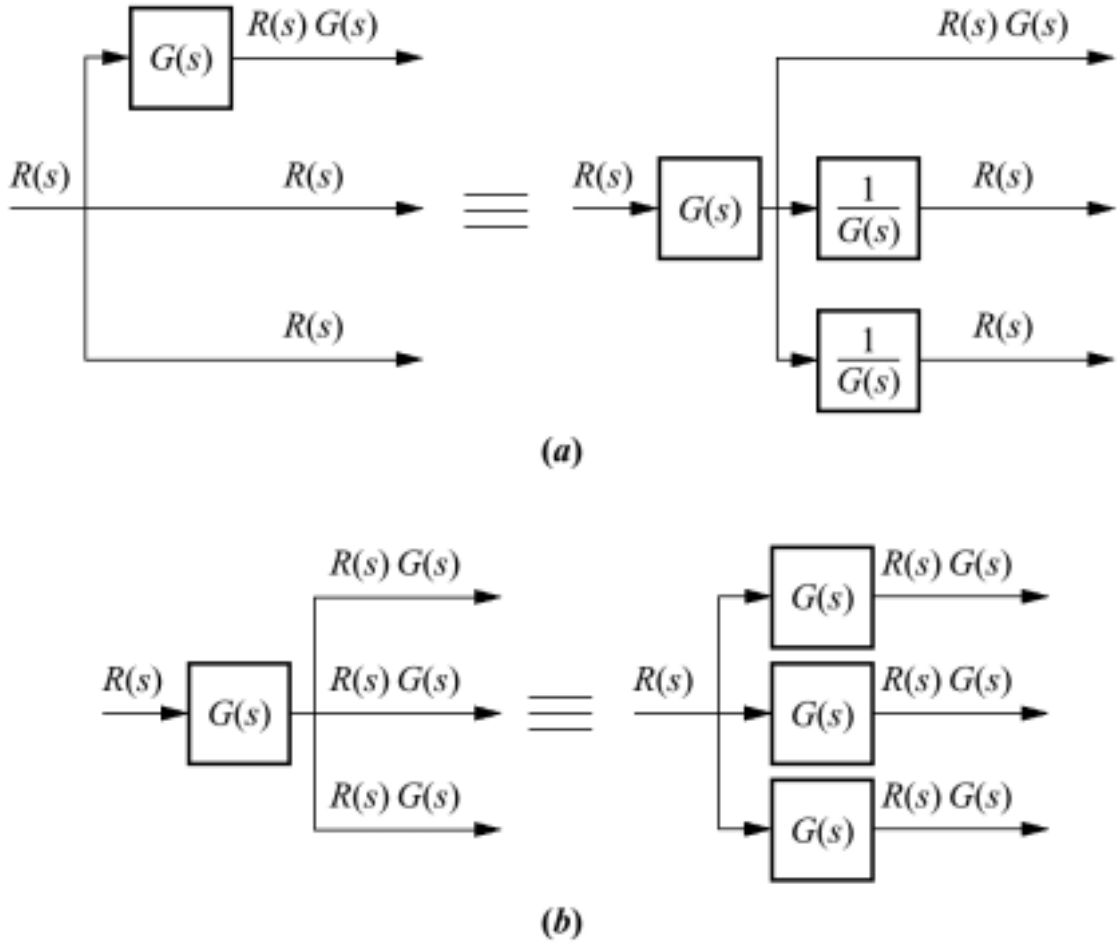


Figure 5.9
Block diagram
for Example5.1

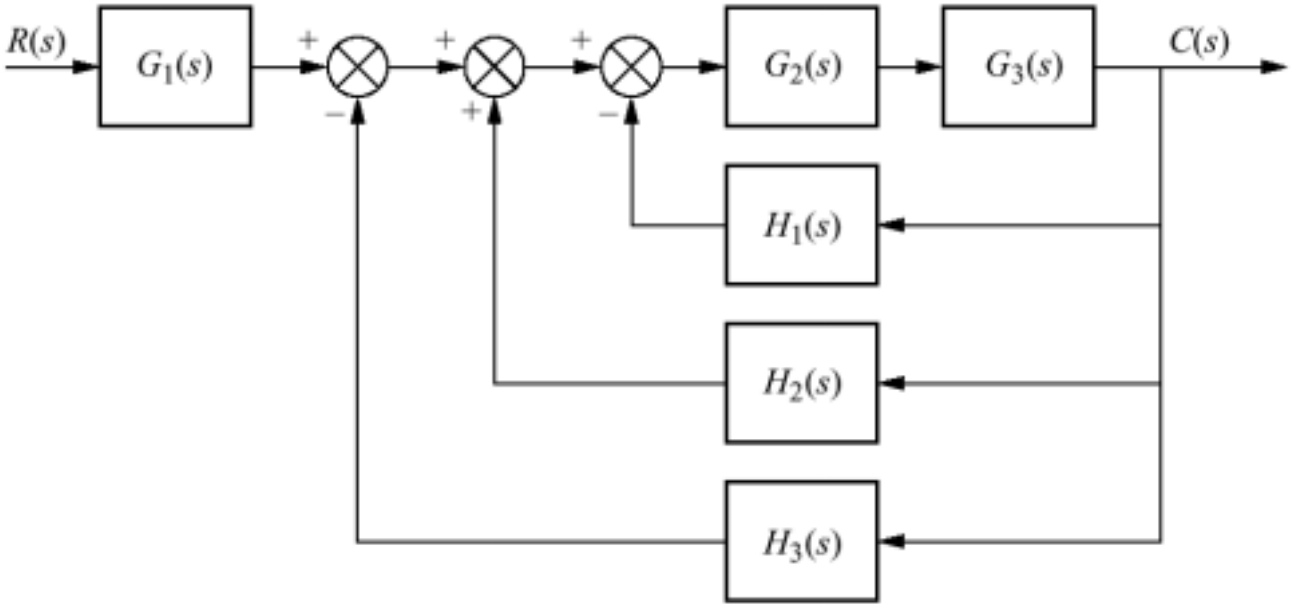


Figure 5.10
Steps in solving Example 5.1:
a. collapse summing junctions;
b. form equivalent cascaded system in the forward path and equivalent parallel system in the feedback path;
c. form equivalent feedback system and multiply by cascaded $G_1(s)$

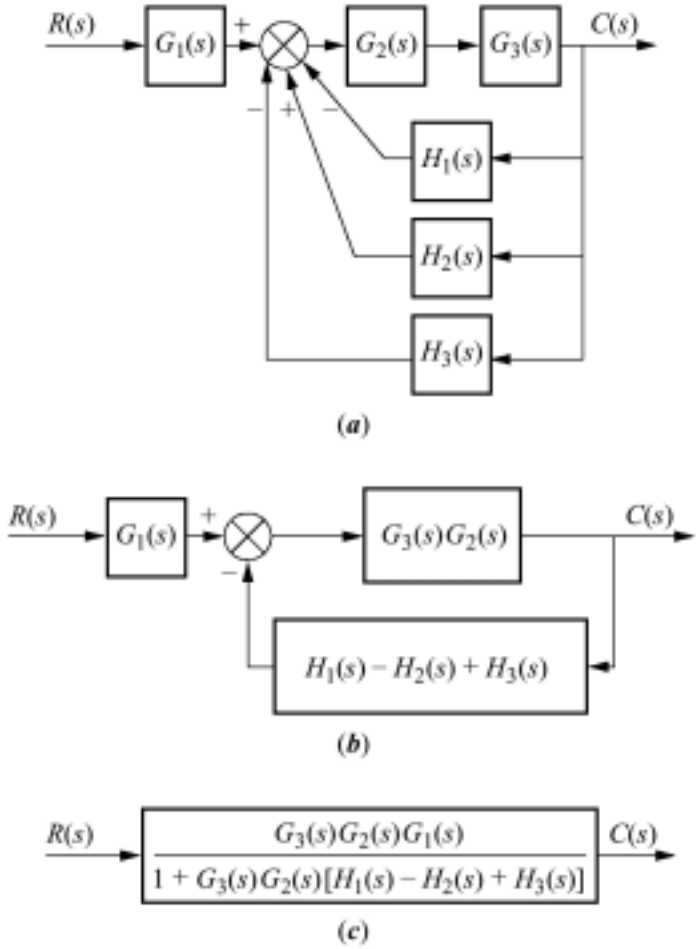


Figure 5.11
Block diagram for
Example 5.2

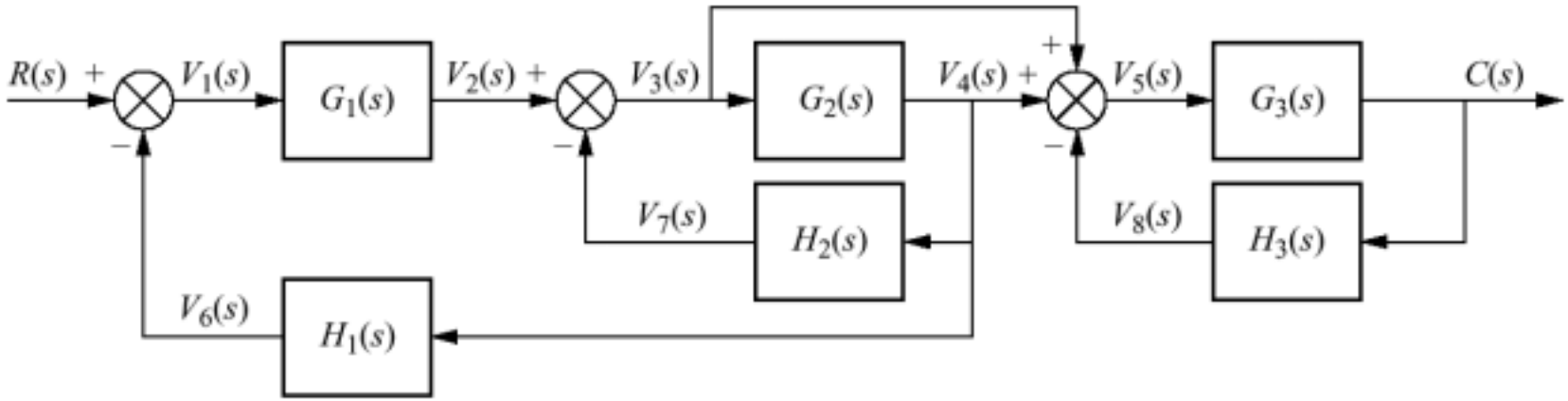


Figure 5.12
Steps in the block diagram reduction for Example 5.2

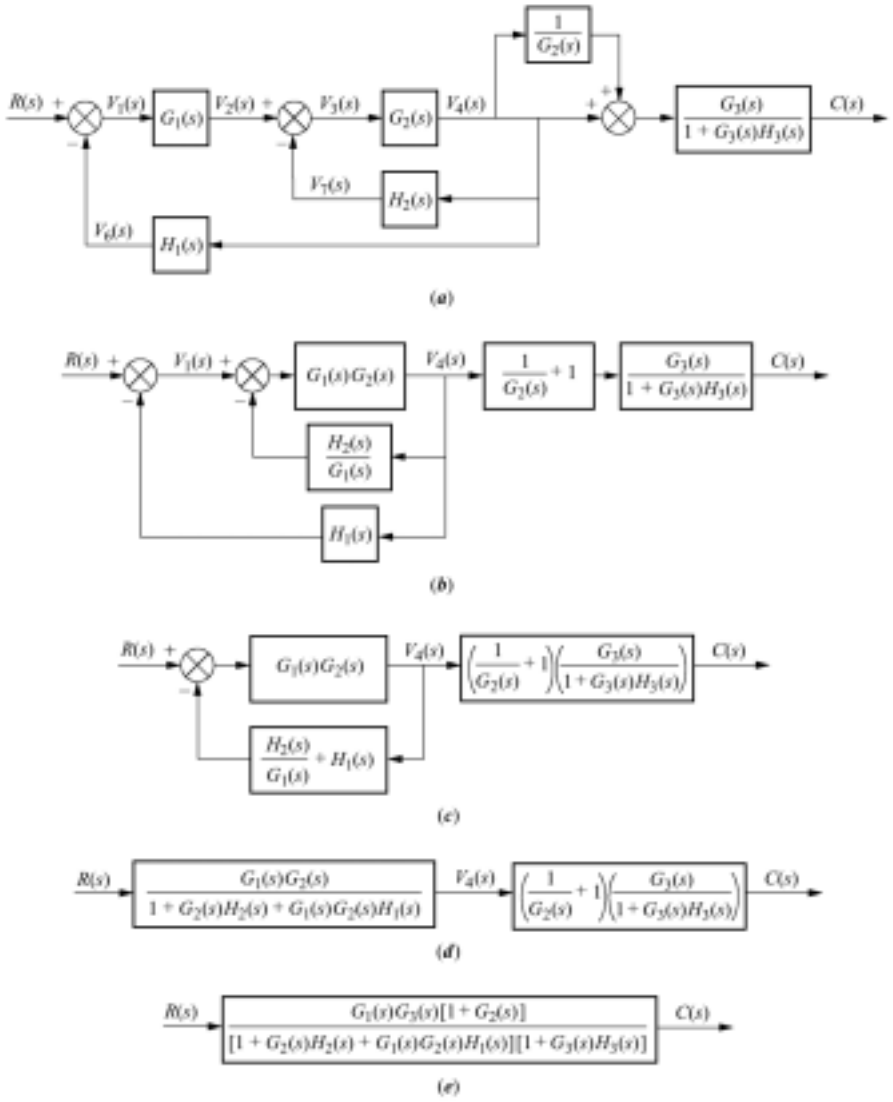


Figure 5.13
Block diagram for Skill-Assessment Exercise 5.1

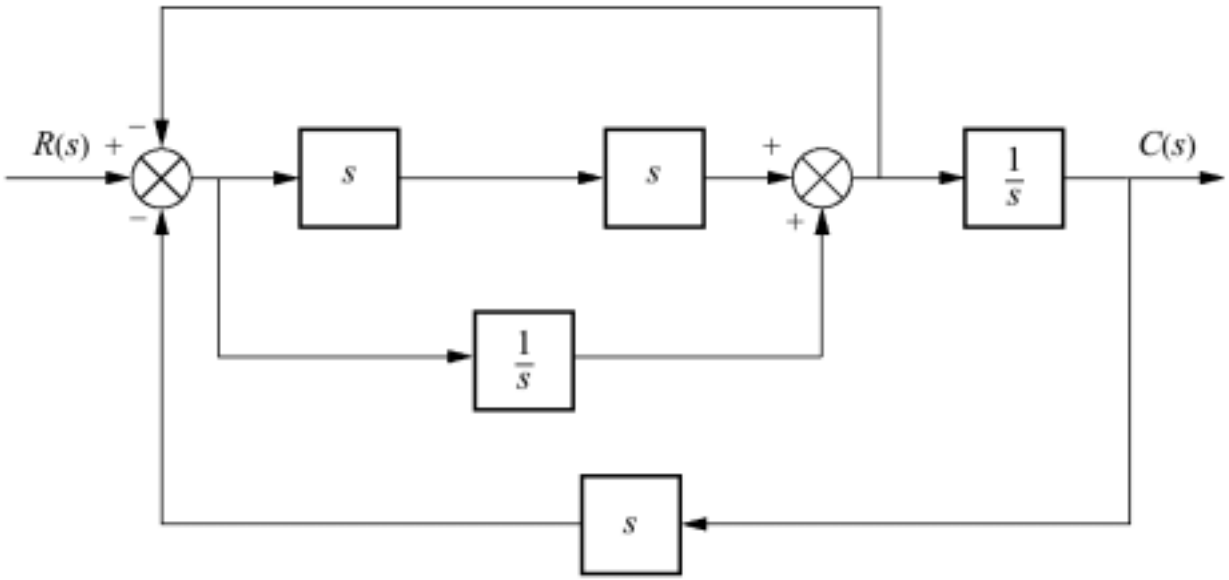


Figure 5.14
Second-order feedback control system

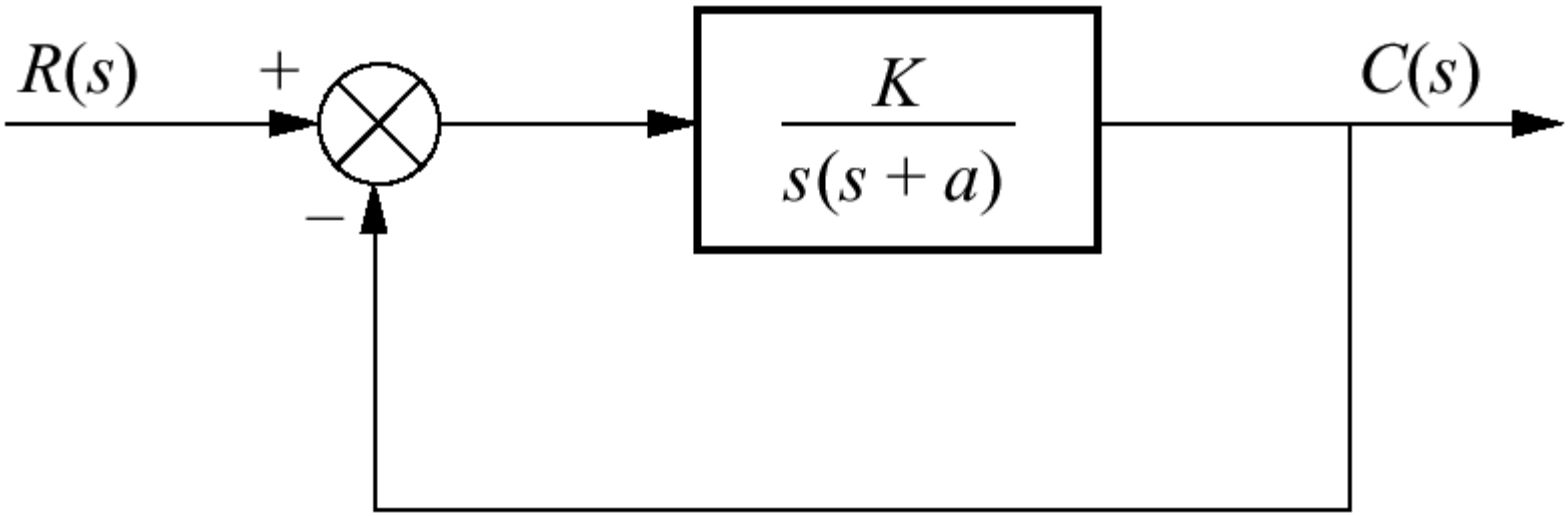


Figure 5.15
Feedback system for
Example 5.3

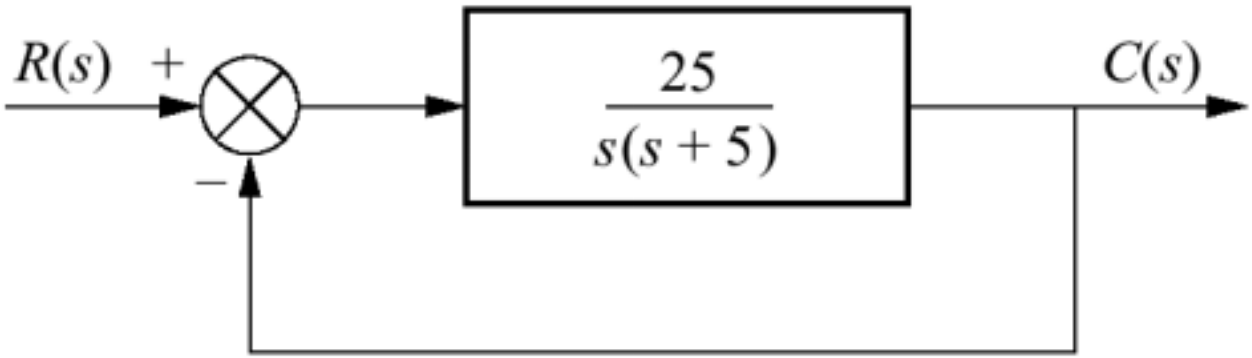


Figure 5.16
Feedback system for
Example 5.4

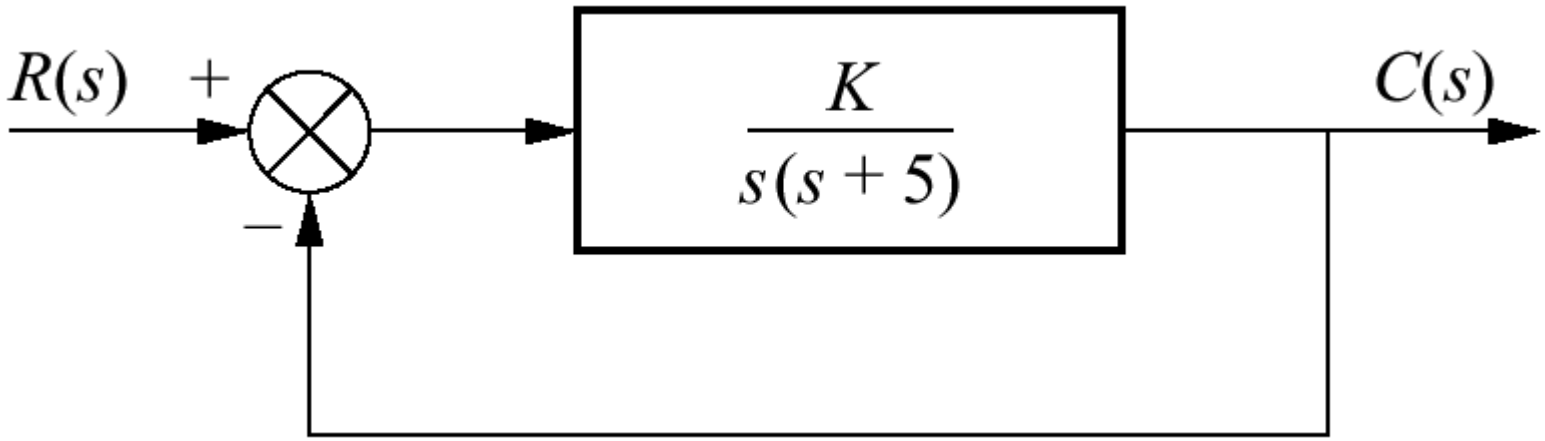
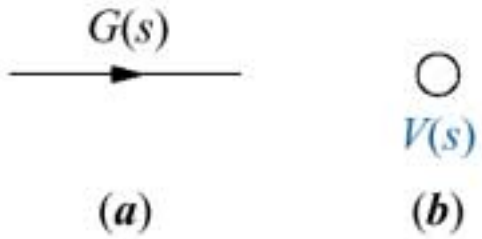


Figure 5.17
Signal-flow graph components:
a. system;
b. signal;
c. interconnection of systems and signals



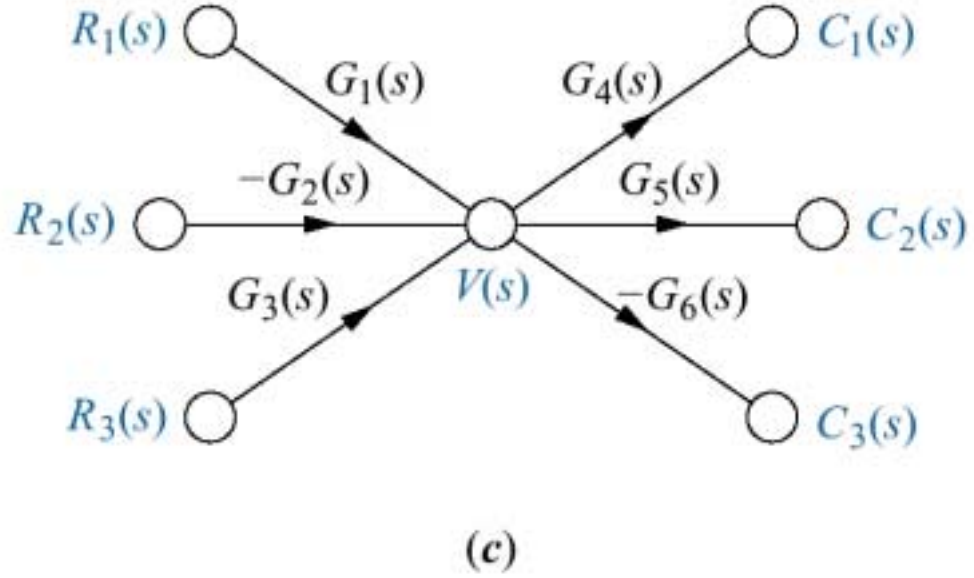


Figure 5.18
Building signal-flow graphs:
a. cascaded system nodes (from Figure 5.3(a));
b. cascaded system signal-flow graph;
c. parallel system nodes (from Figure 5.5(a));
d. parallel system signal-flow graph;
e. feedback system nodes (from Figure 5.6(b));
f. feedback system signal-flow graph

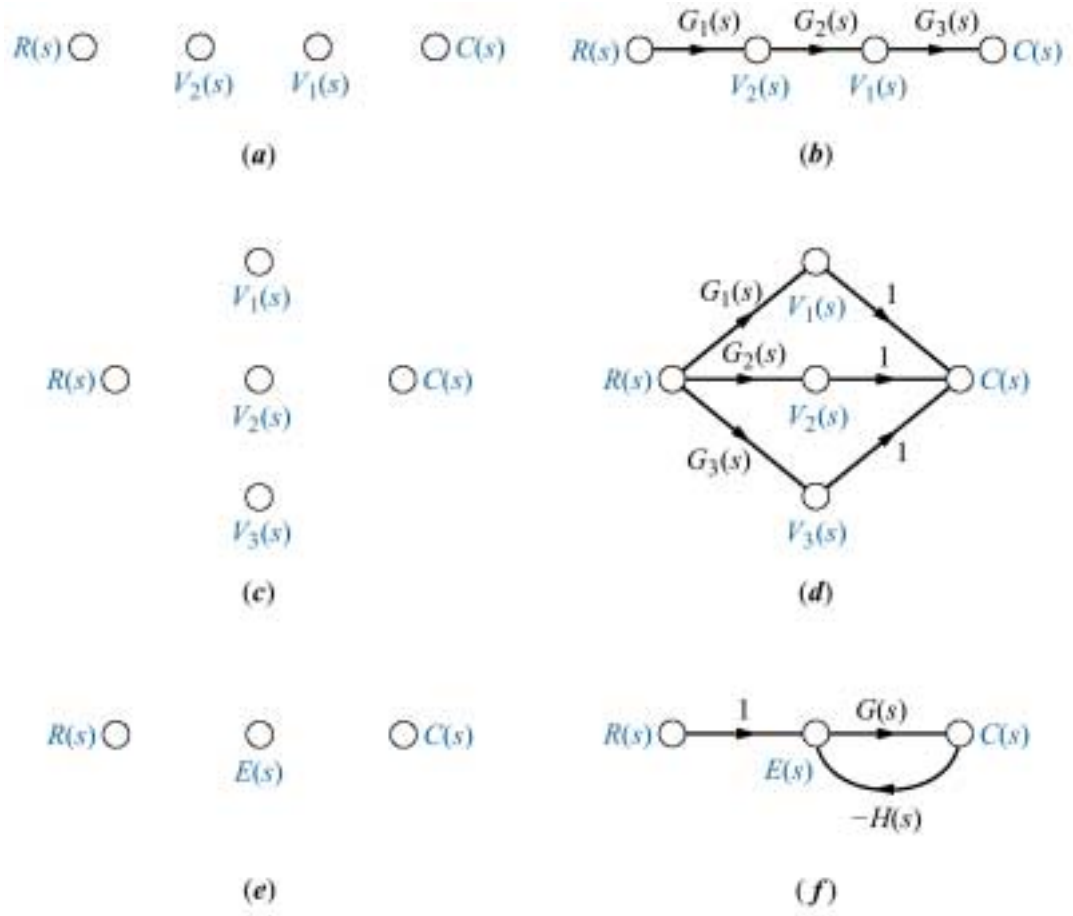


Figure 5.19
Signal-flow graph development:
a. signal nodes;
b. signal-flow graph;
c. simplified signal-flow graph

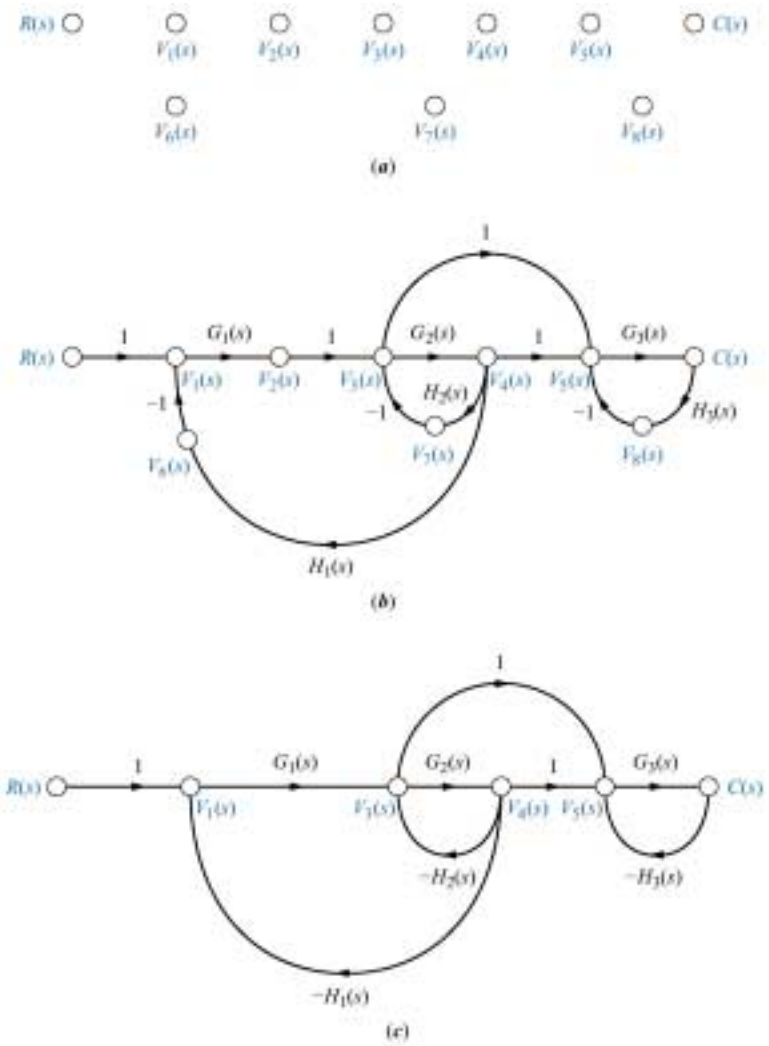


Figure 5.20
Signal-flow graph for demonstrating Mason's rule

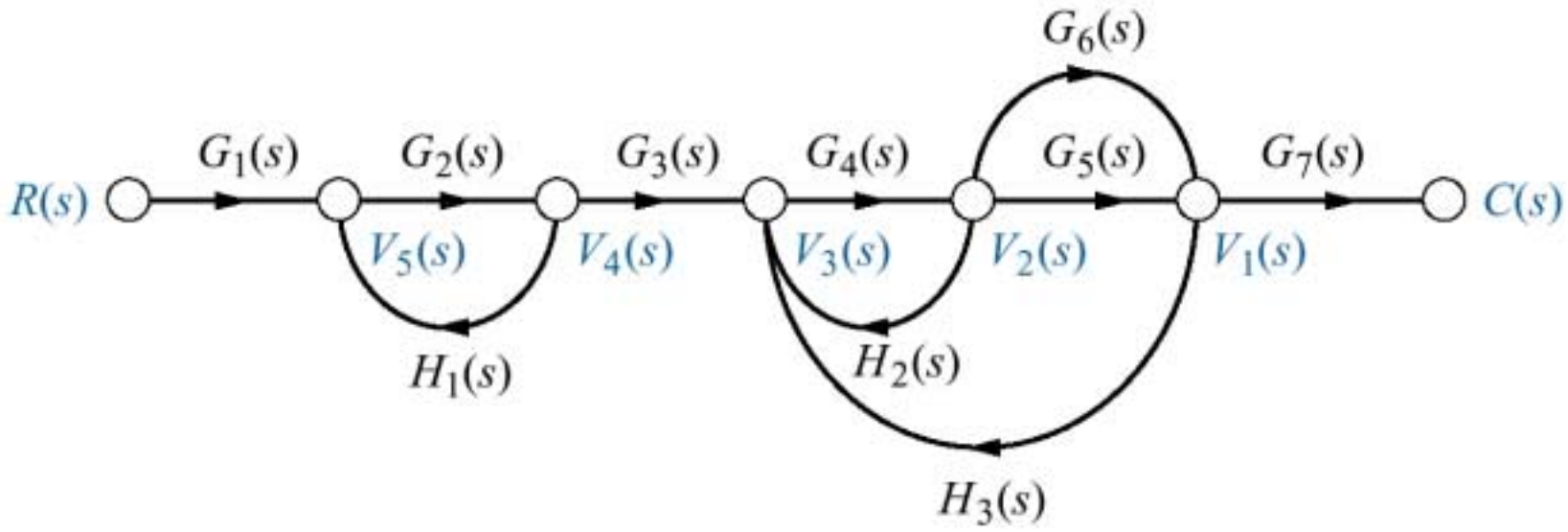


Figure 5.21
Signal-flow graph for
Example 5.7

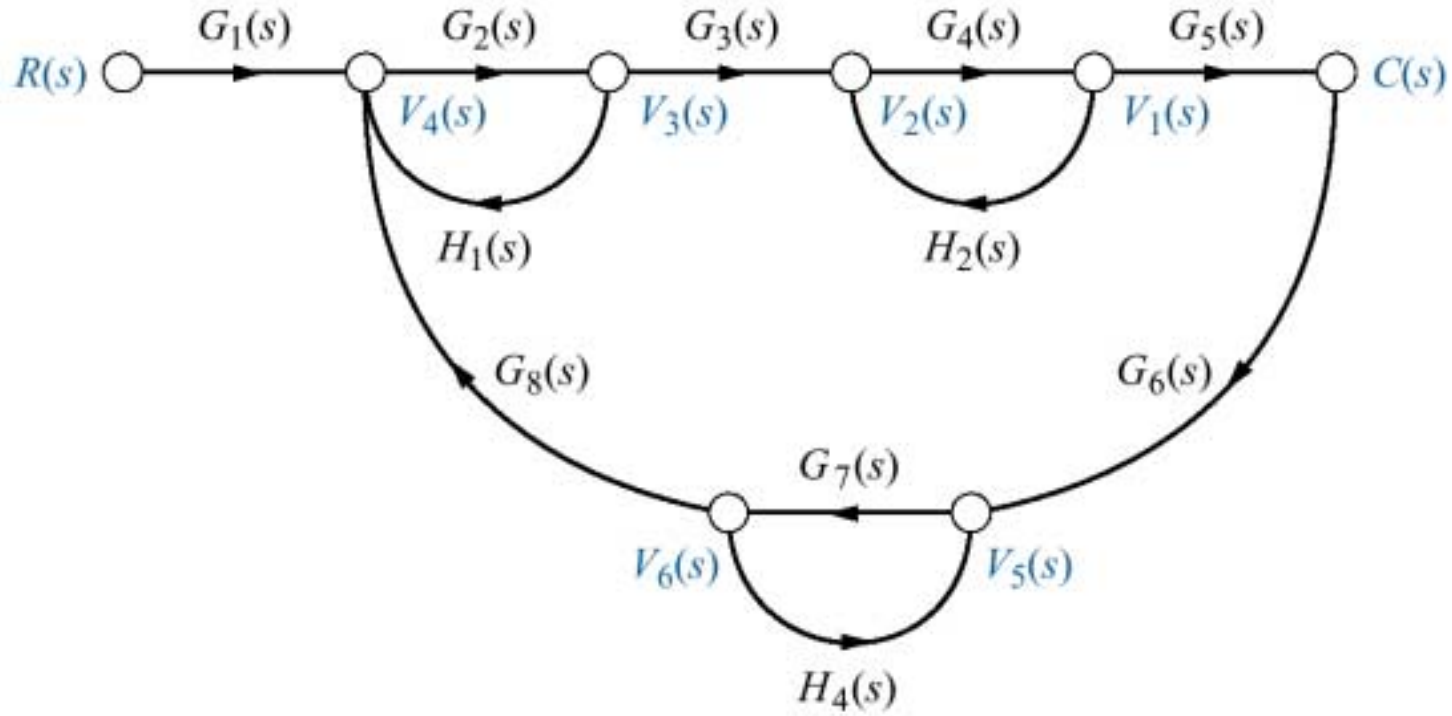


Figure 5.22
Stages of development of a signal-flow graph for the system of Eqs. 5.36:
a. place nodes;
b. interconnect state variables and derivatives;
c. form dx_1/dt ;
d. form dx_2/dt
(figure continues)

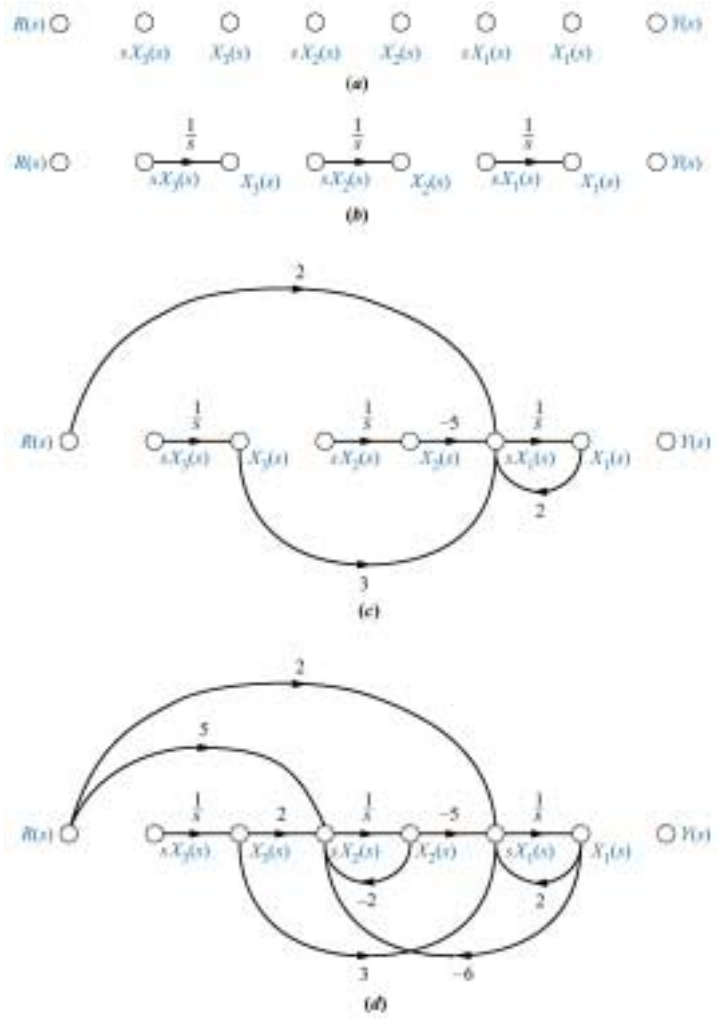


Figure 5.22 (continued)
e. form dx_3/dt;
f. form output

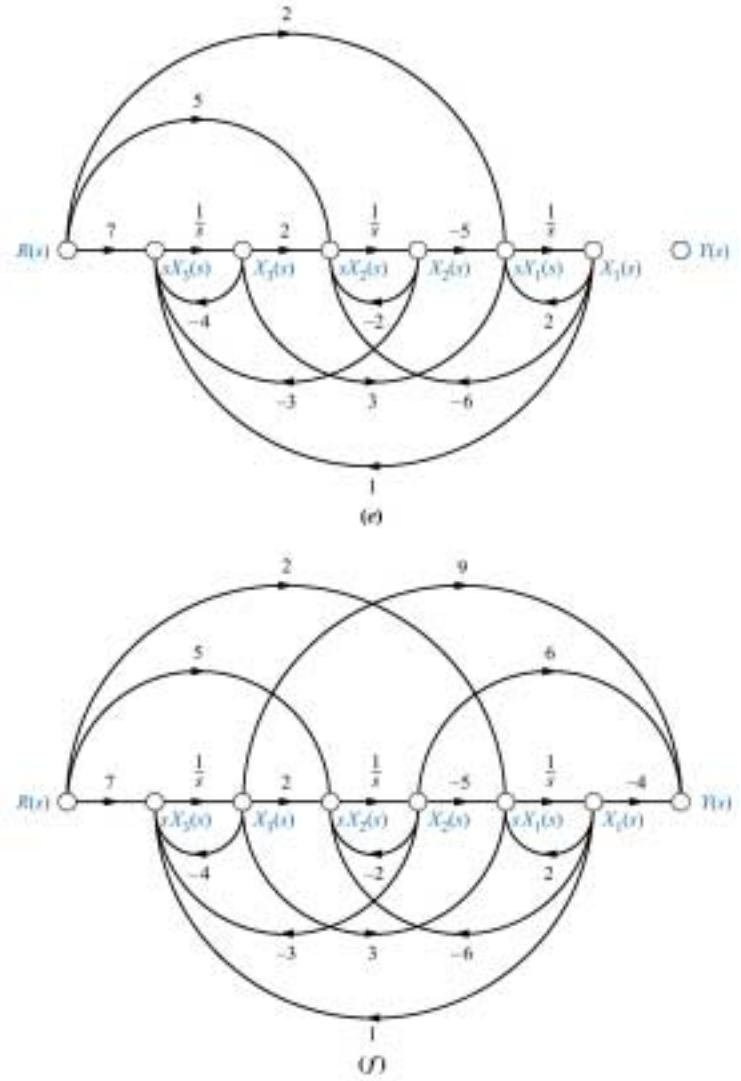


Figure 5.23
Representation of Figure 3.10 system as cascaded first-order systems

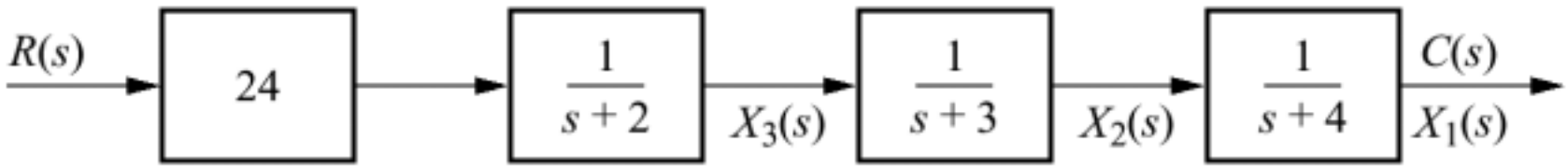


Figure 5.24
a. First-order subsystem;
b. signal-flow graph for Figure 5.23 system

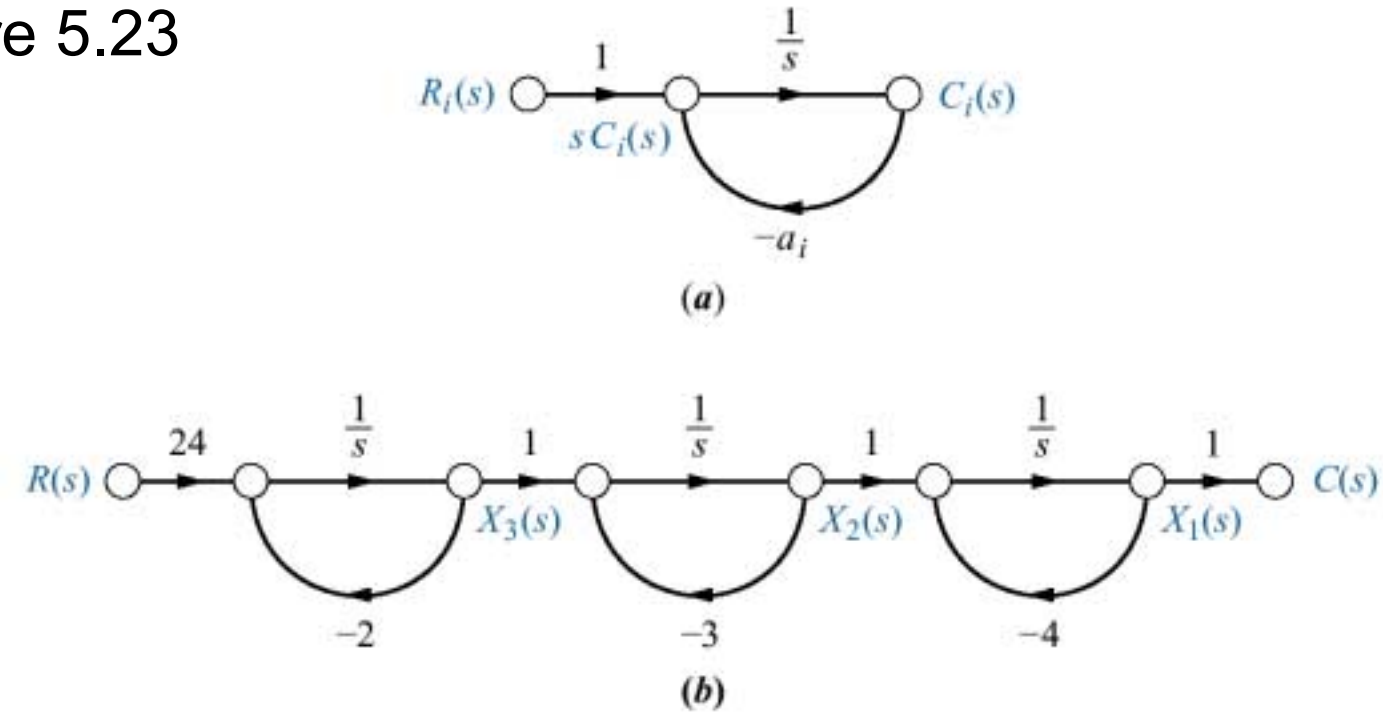


Figure 5.25
Signal-flow representation of Eq. (5.45)

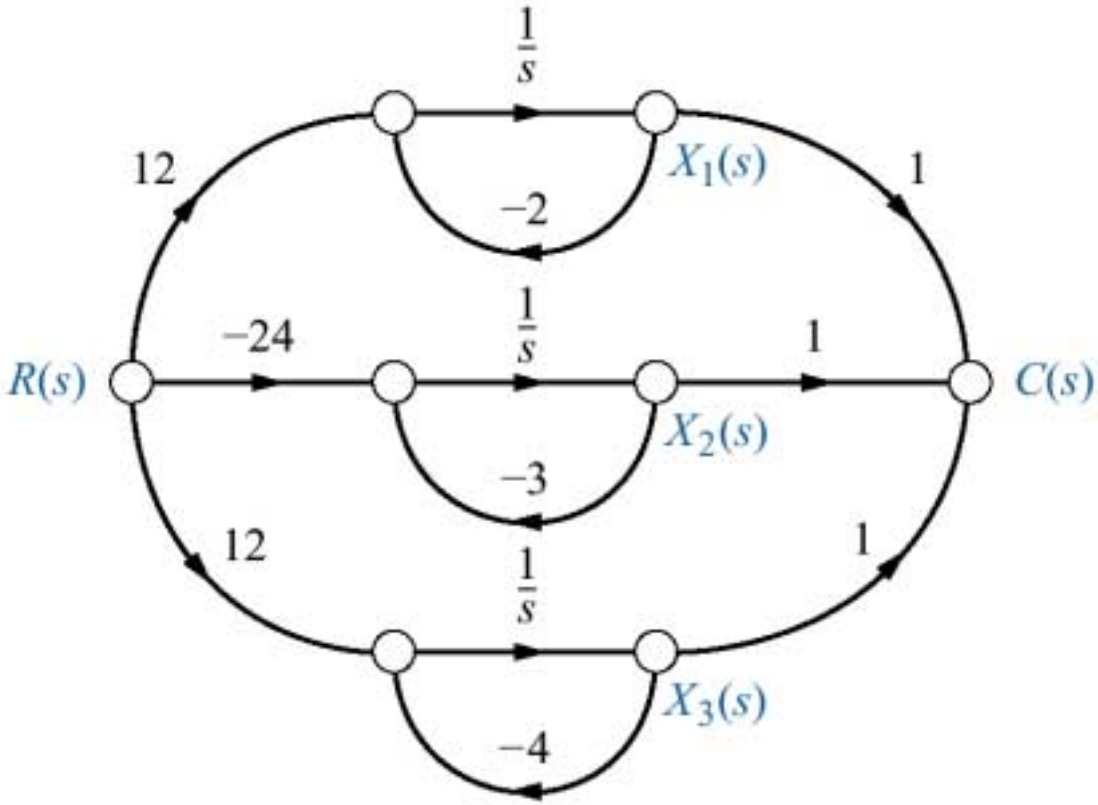


Figure 5.26
Signal-flow representation of Eq. (5.52)

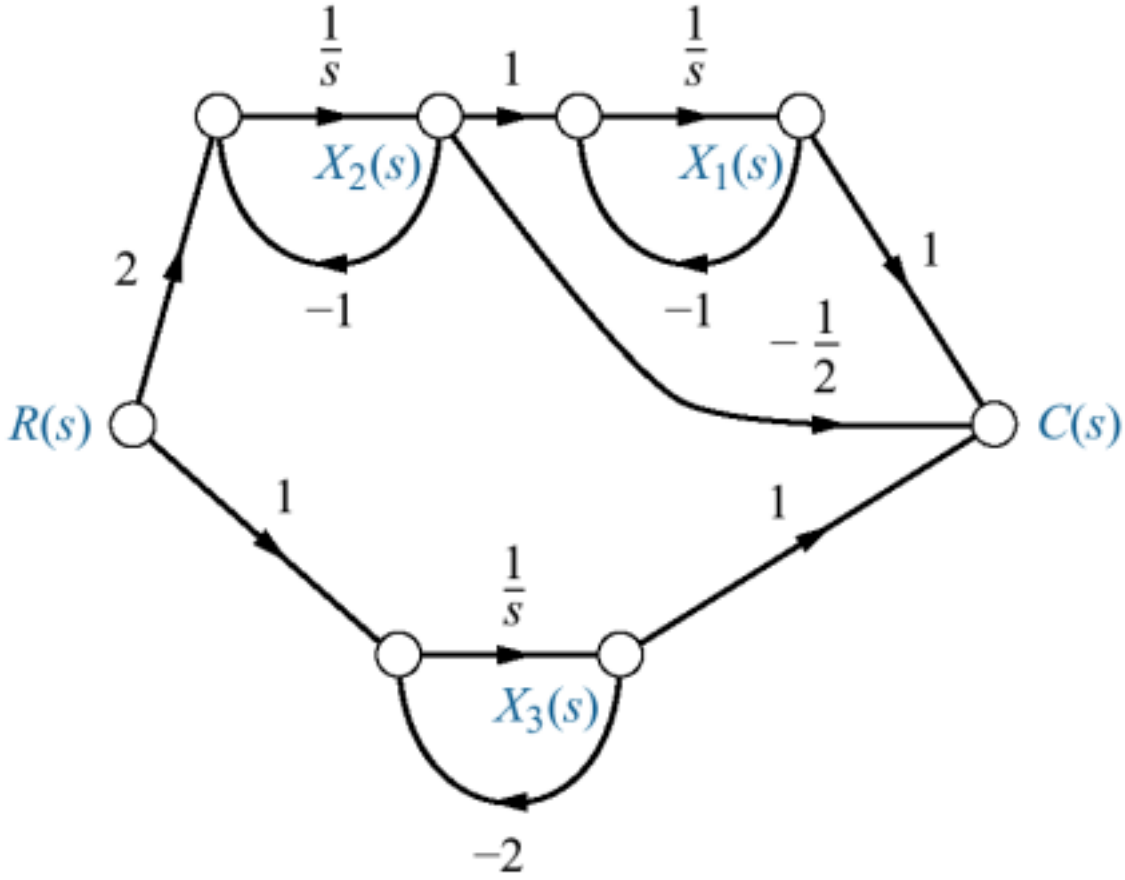


Figure 5.27
Signal-flow graphs for obtaining forms for $G(s) = C(s)/R(s) = (s^2 + 7s + 2)/(s^3 + 9s^2 + 26s + 24)$:
a. phase-variable form;
b. controller canonical form

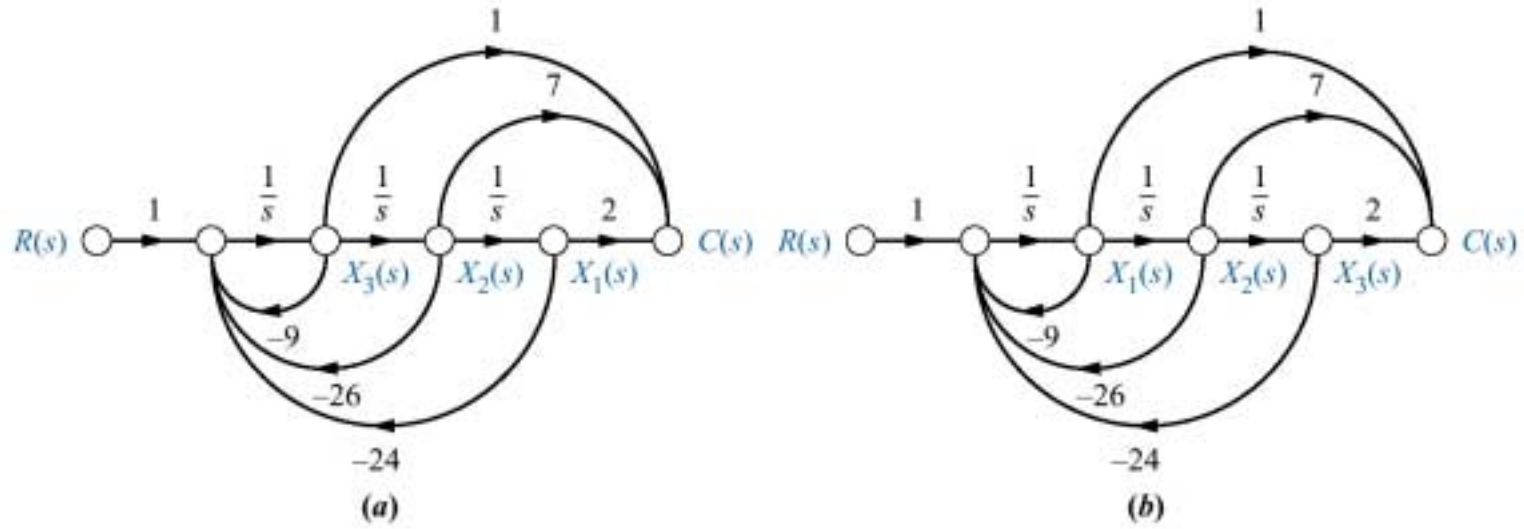


Figure 5.28
Signal-flow graph for observer canonical form variables:
a. planning;
b. implementation

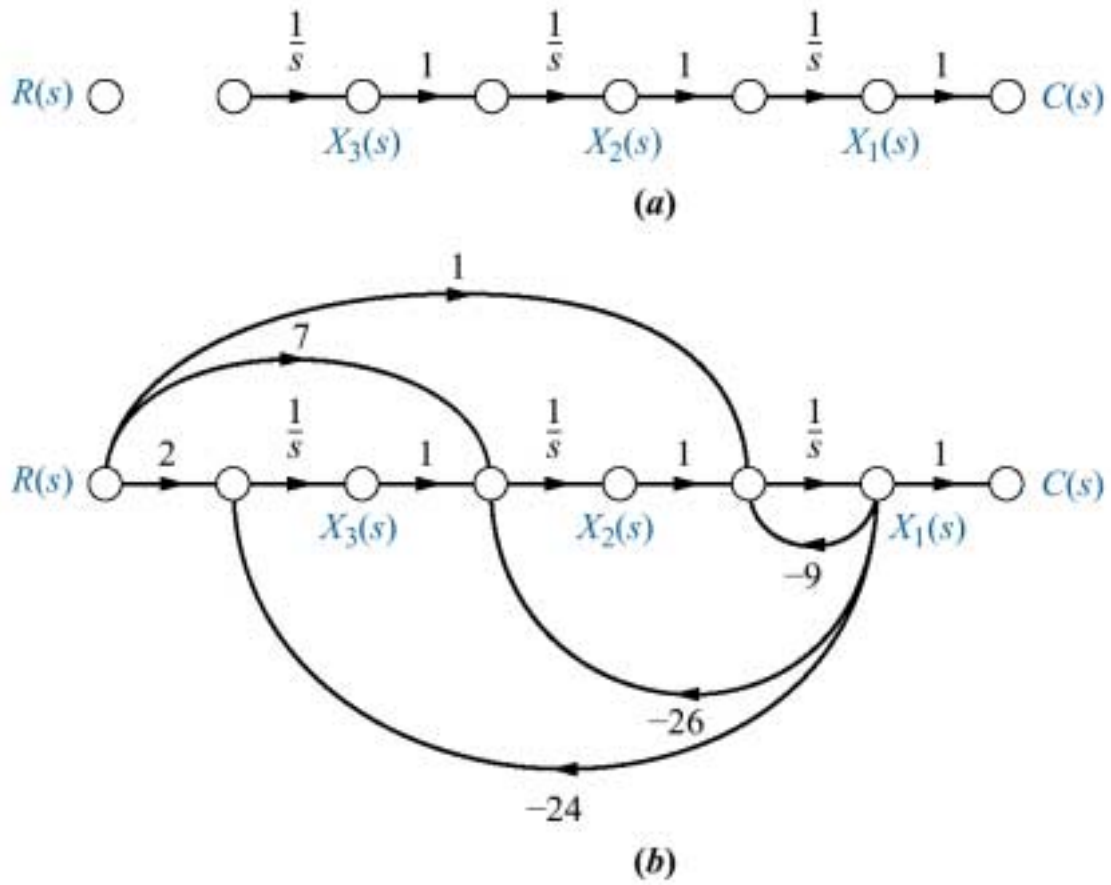


Figure 5.29
Feedback
control system
for Example 5.8

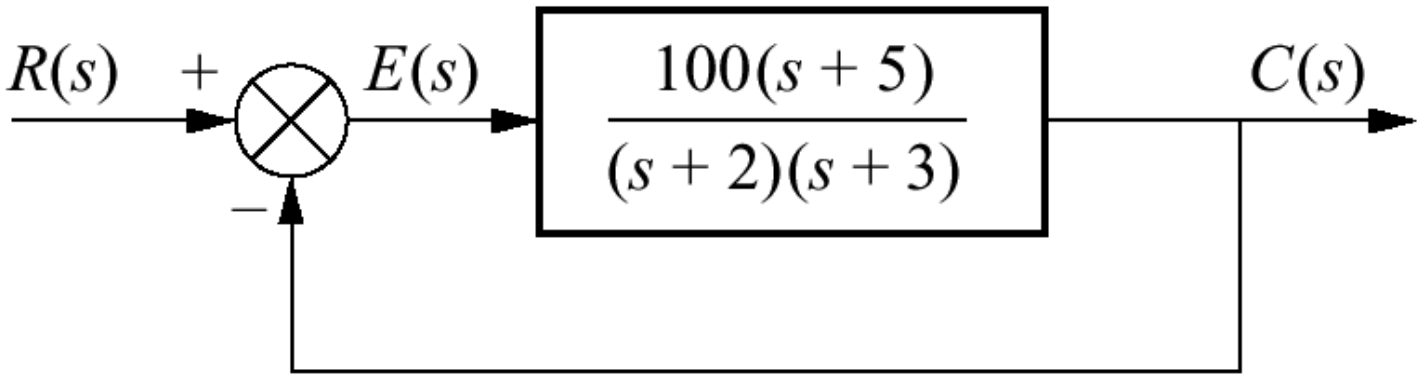


Figure 5.30
Creating a signal-flow graph for the Figure 5.29 system:
a. forward transfer function;
b. complete system

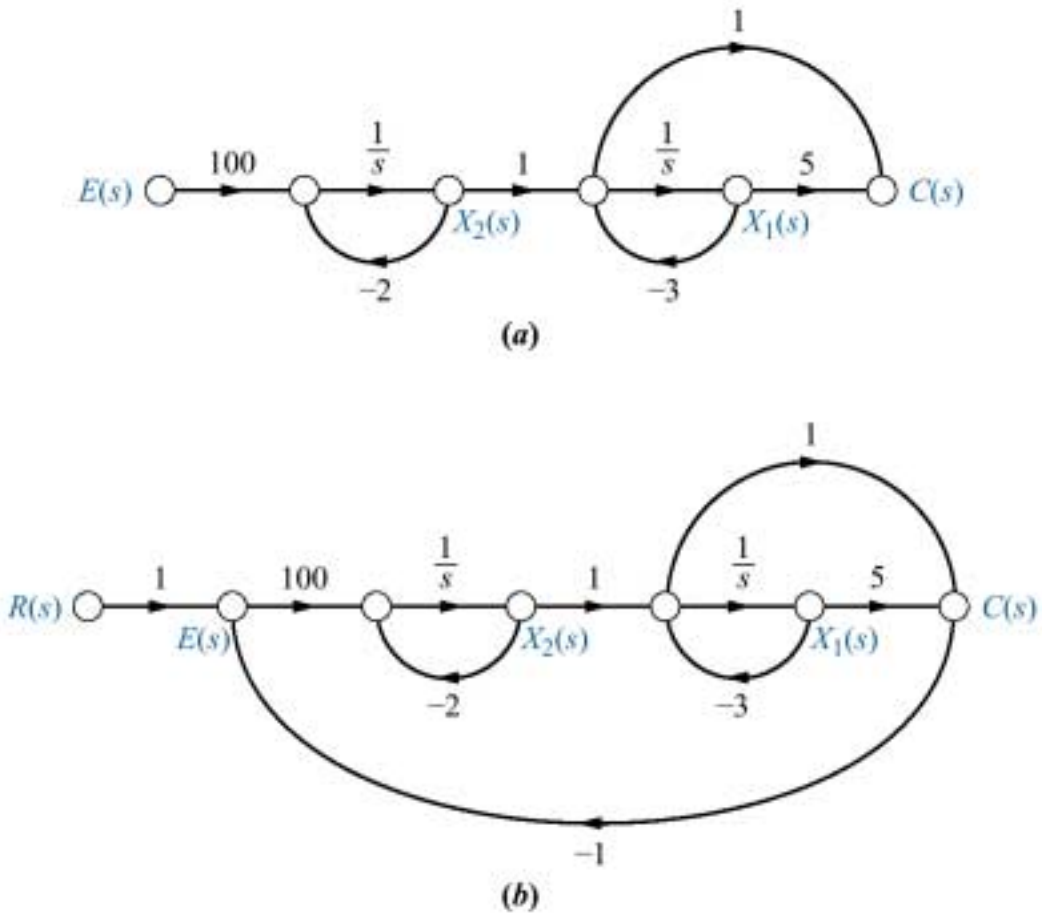


Figure 5.31
State-space forms for
C(s)/R(s) =
(s+ 3)/[(s+ 4)(s+ 6)].
Note: y = c(t)

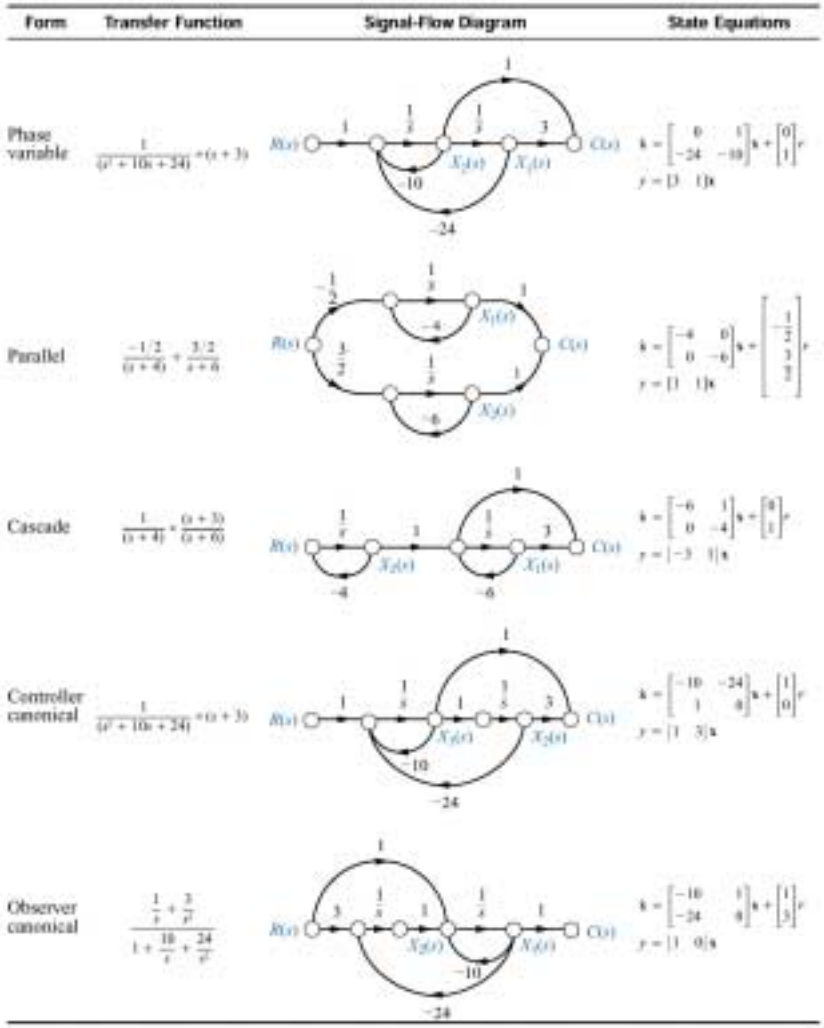


Figure 5.32
State-space transformations

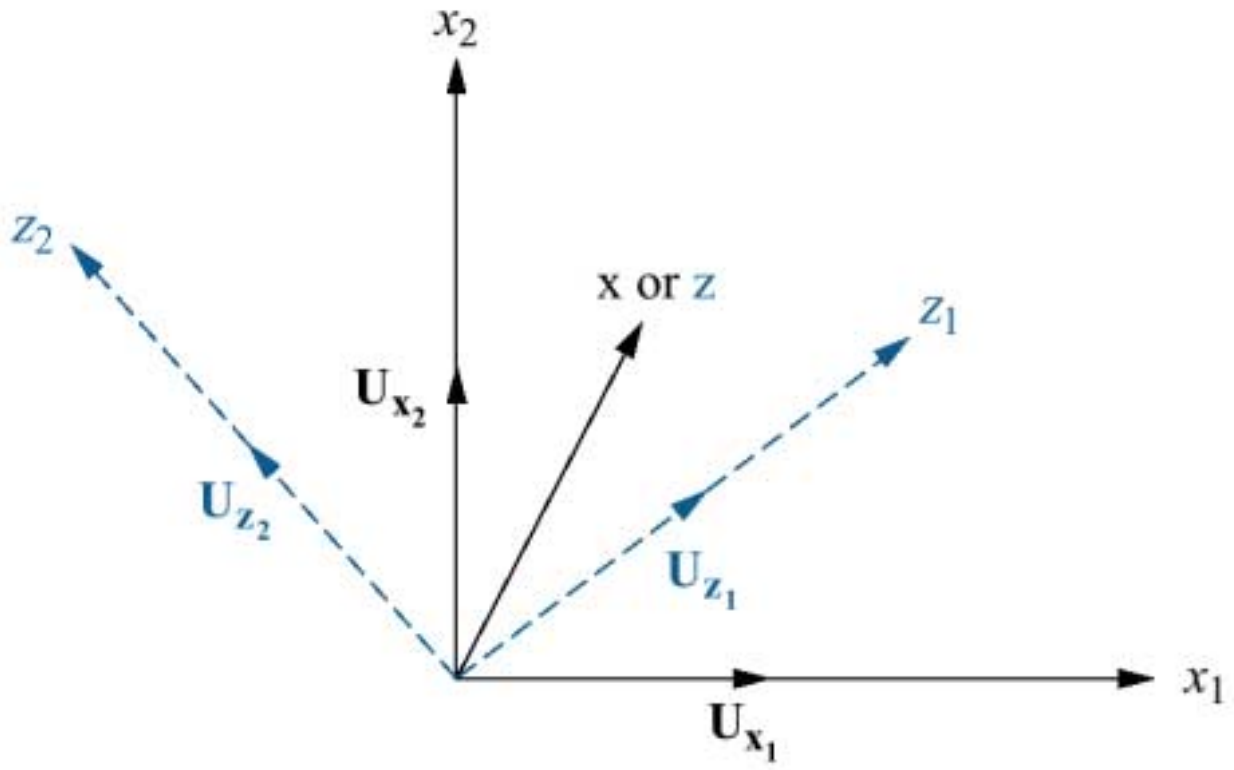


Figure 5.33
To be an eigenvector, the transformation **Ax** must be collinear with **x**; thus in (*a*) **x** is not an eigenvector; in (*b*), it is.

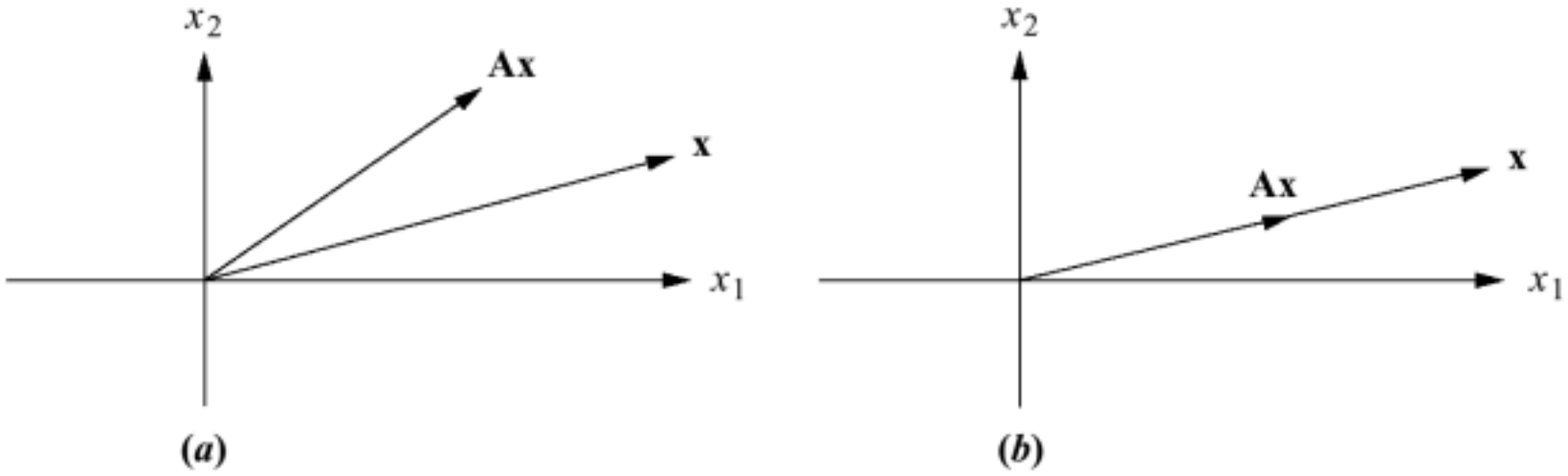


Figure 5.34
Alvin, a manned submersible, explored the wreckage of the *Titanic* with a tethered robot, *Jason Junior.*

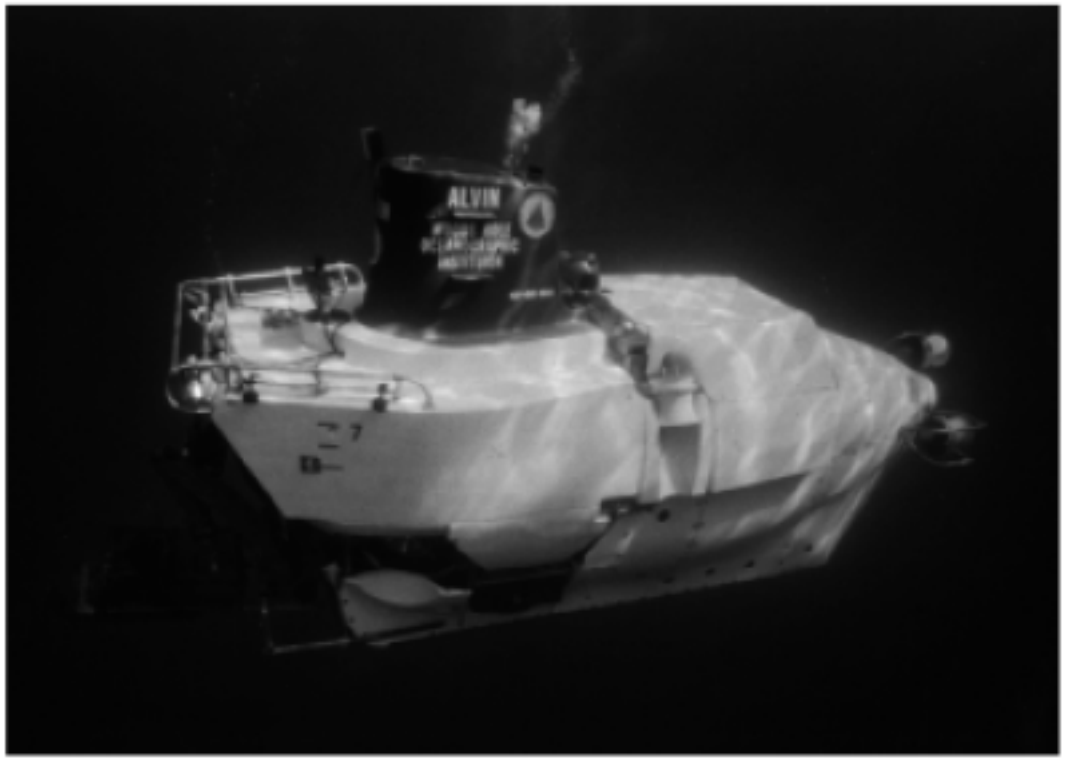


Figure 5.35
Block diagram reduction for the antenna azimuth position control system:
a. original;
b. pushing input potentiometer to the right past the summing junction;
c. showing equivalent forward transfer function;
d. final closed-loop transfer function

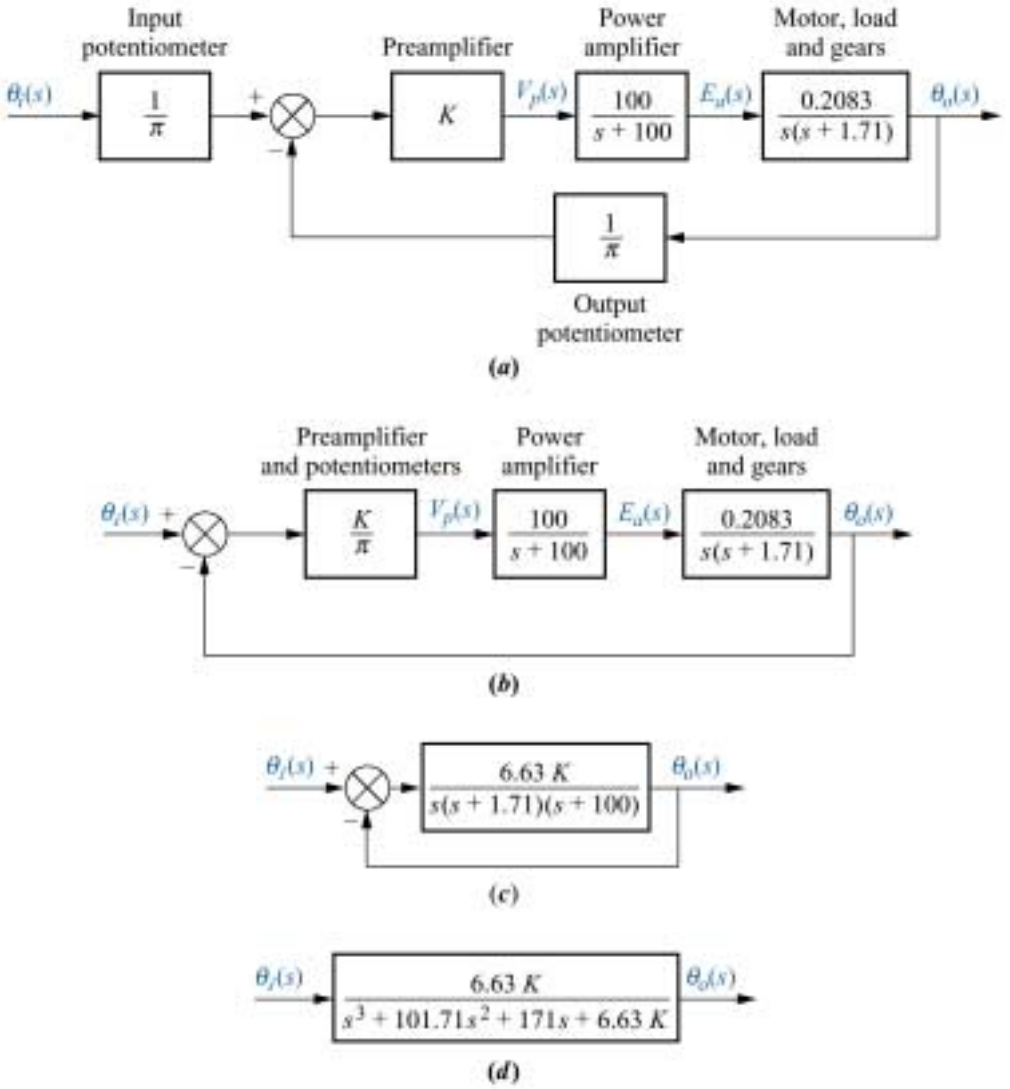


Figure 5.36
Signal-flow graph for the antenna azimuth position control system

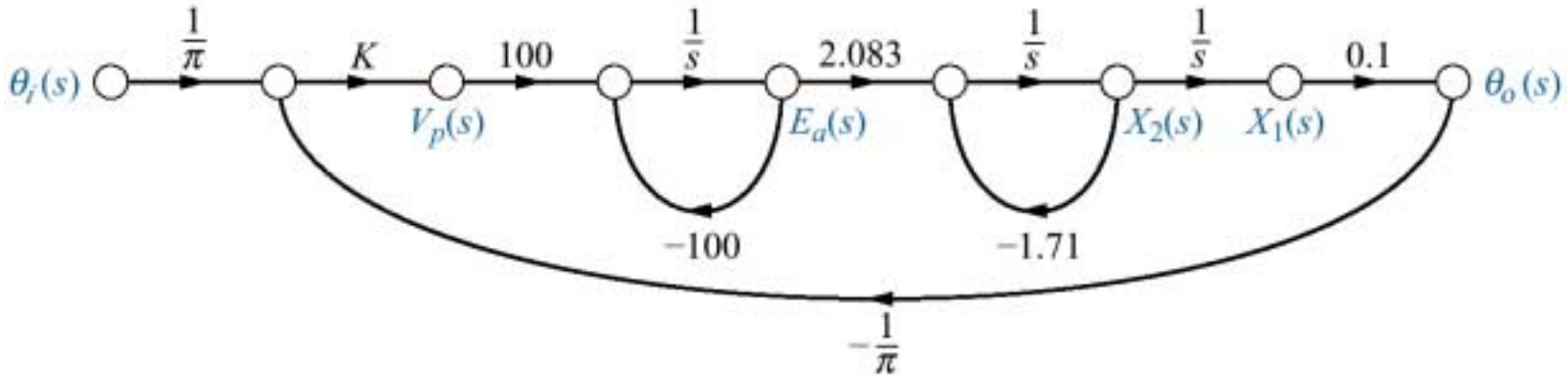


Figure 5.37
Block diagram of the UFSS vehicle's elevator and vehicle dynamics, from which a signal-flow graph can be drawn

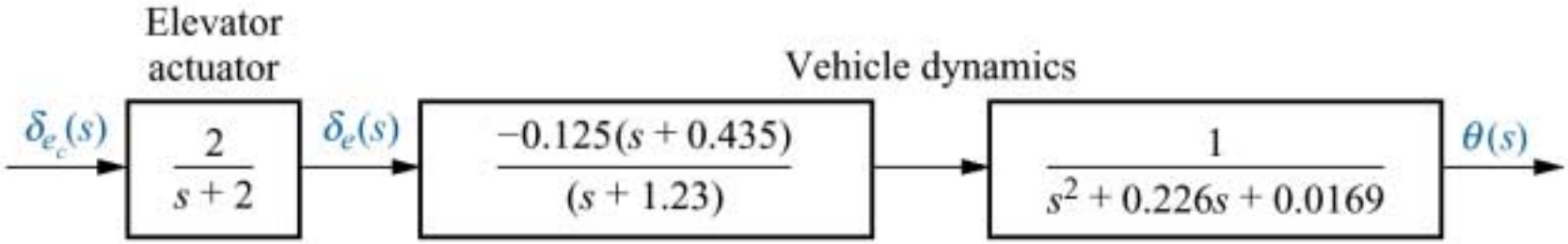


Figure 5.38
Signal-flow graph representation of the UFSS vehicle's pitch-control system:
a. without position and rate feedback;
b. with position and rate feedback
(Note: Explicitly required variables are: $x_1 = q$, $x_2 = dq/dt$, and $x_4 = d_e$)

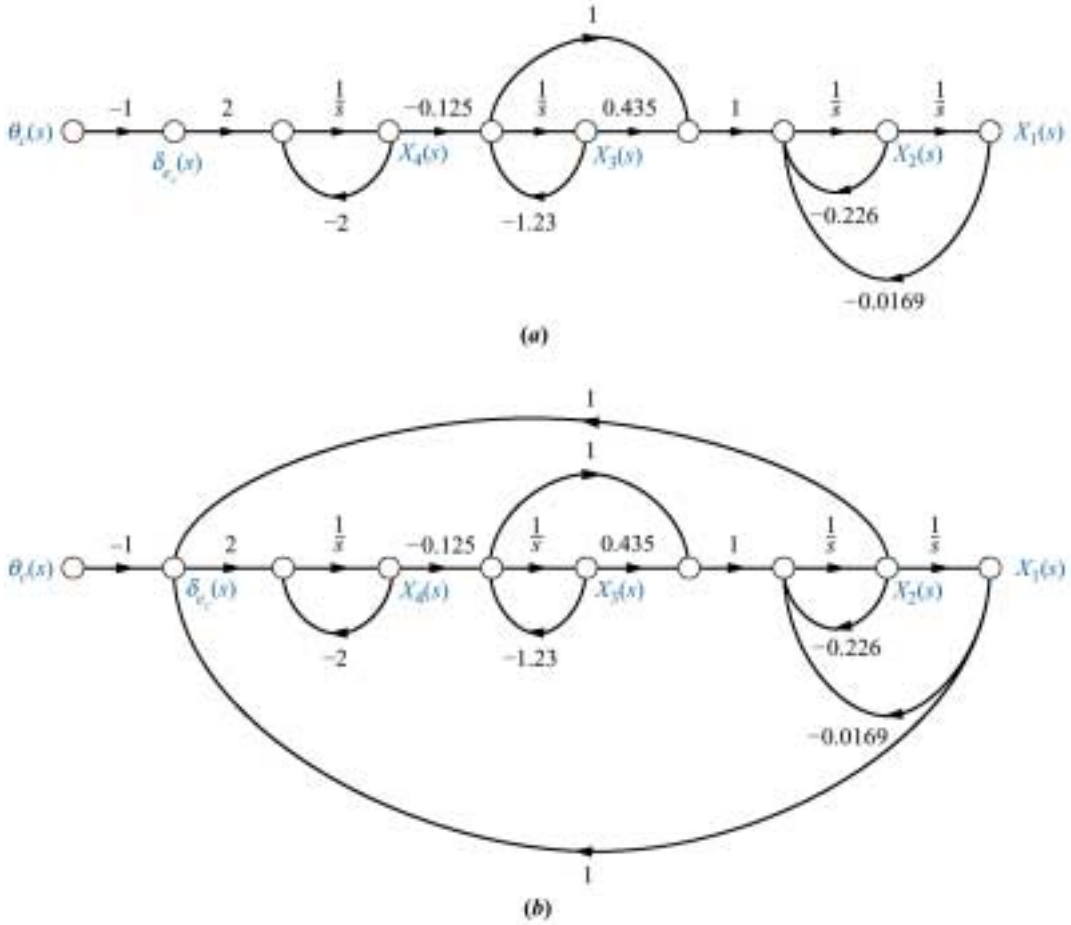


Figure 5.39
Block diagram of the heading control system for the UFSS vehicle

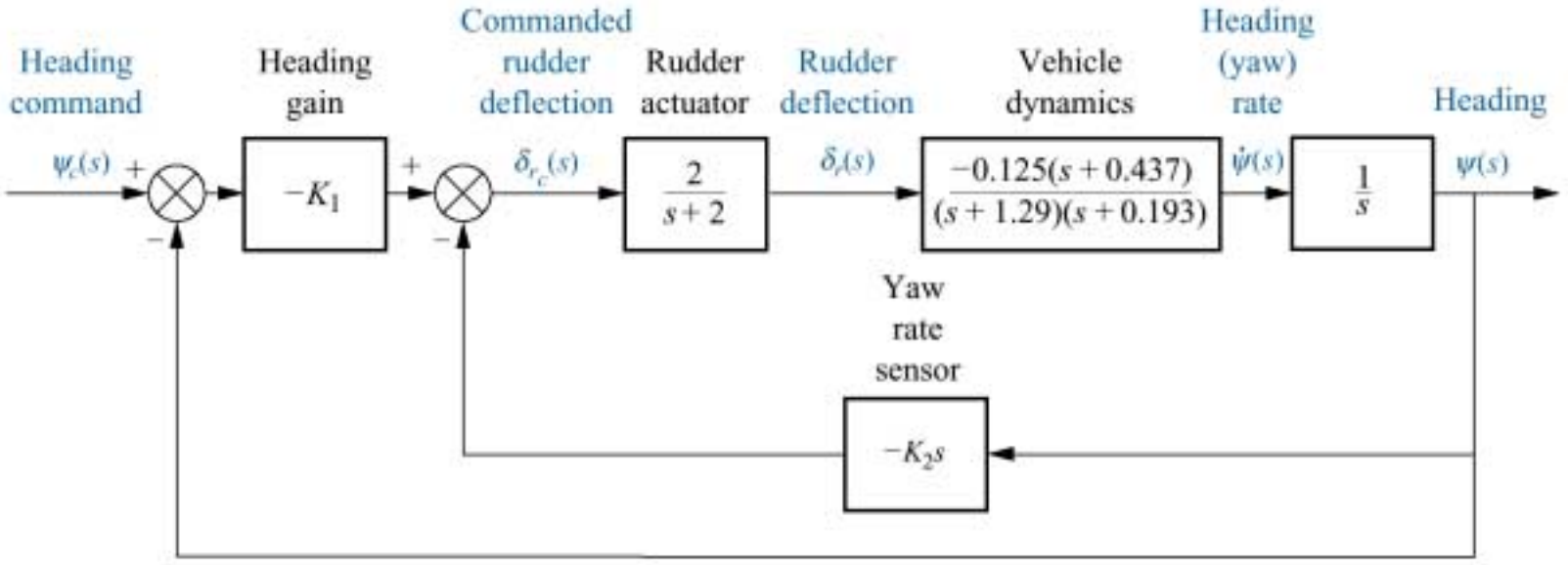


Figure P5.1

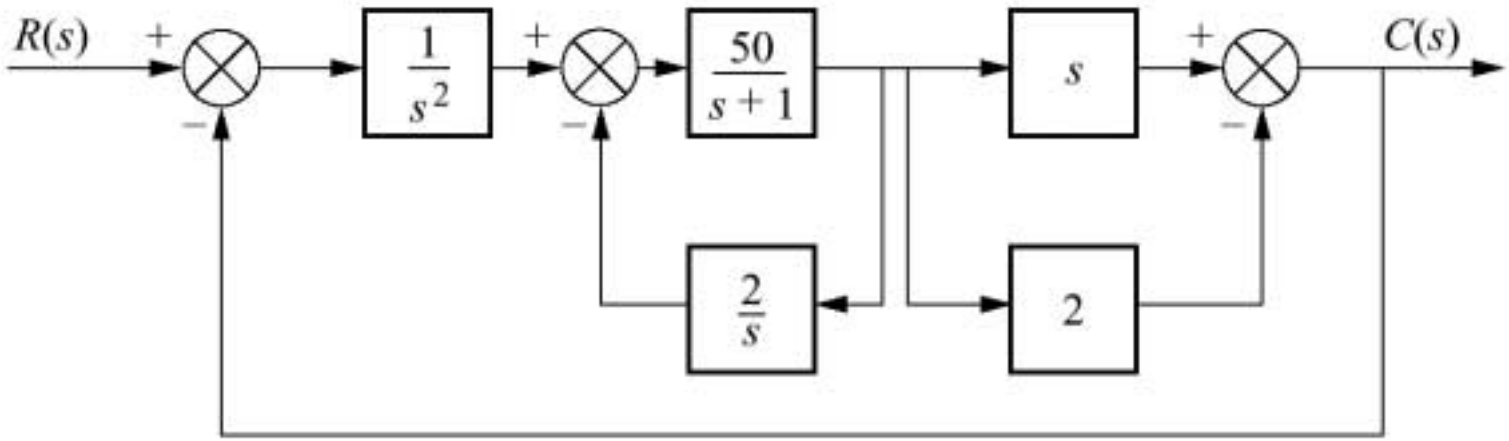


Figure P5.2

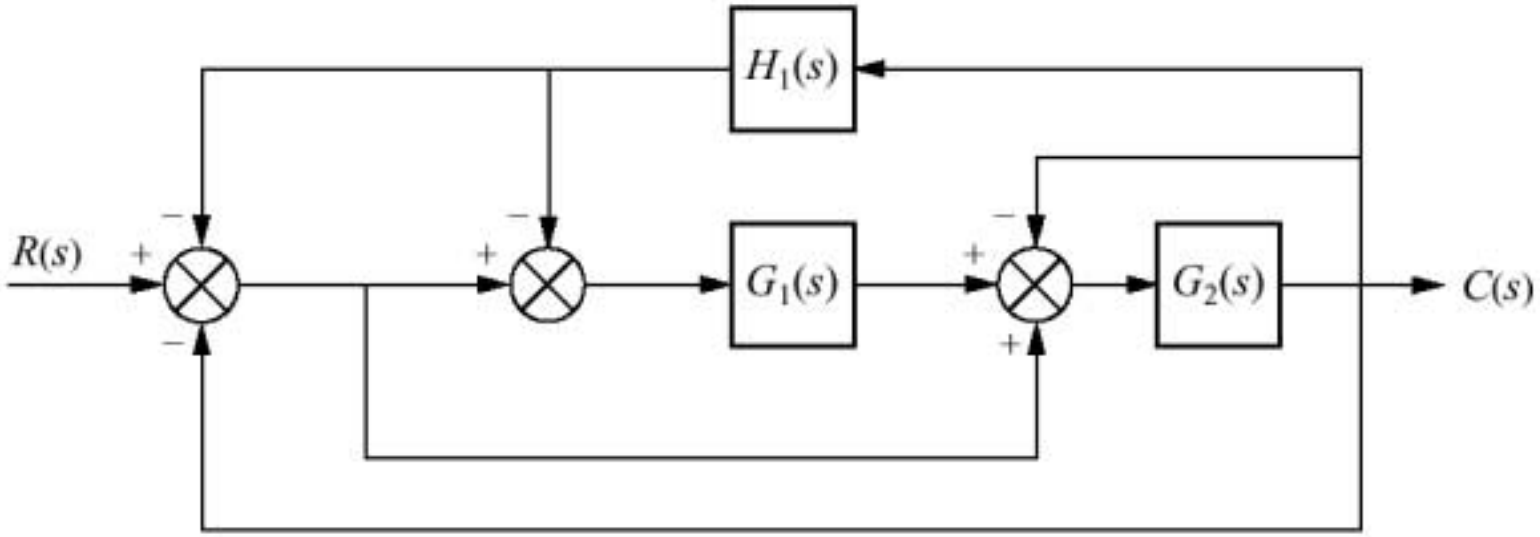


Figure P5.3

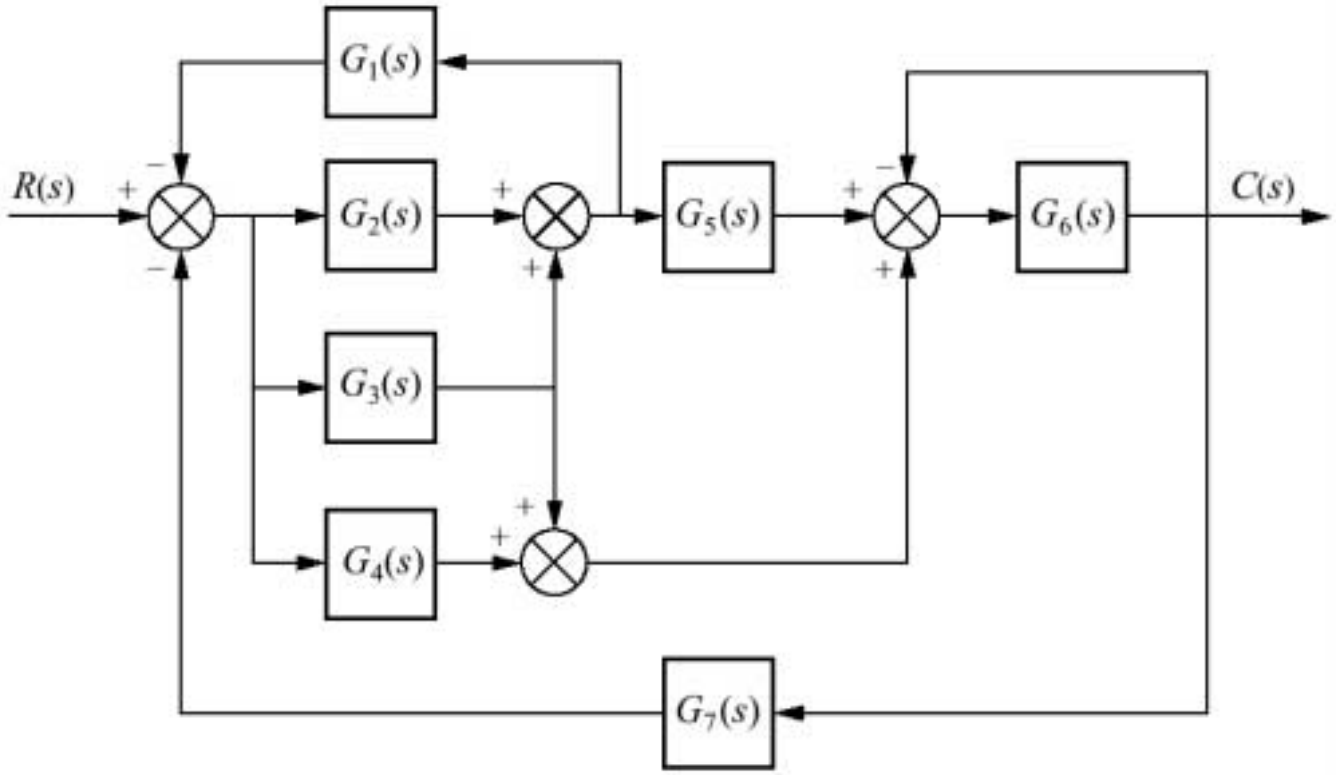


Figure P5.4

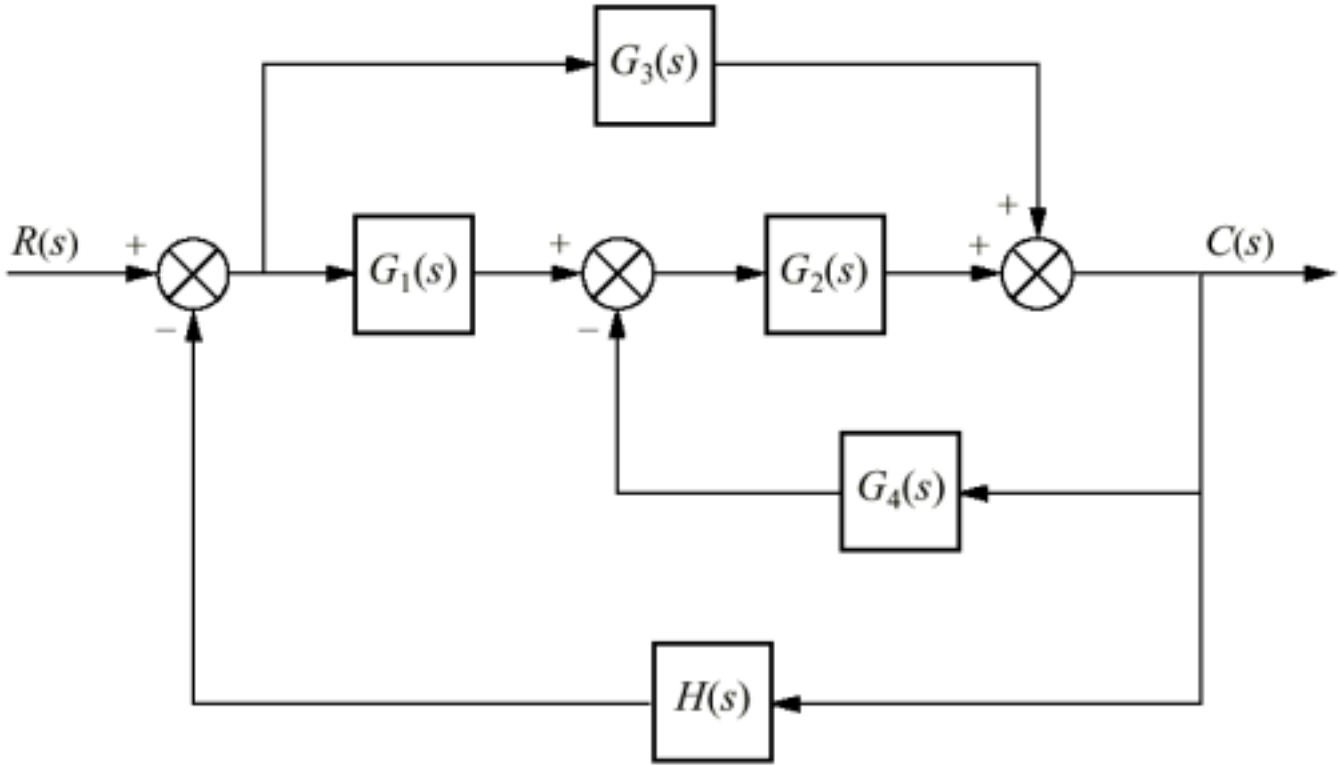


Figure P5.5

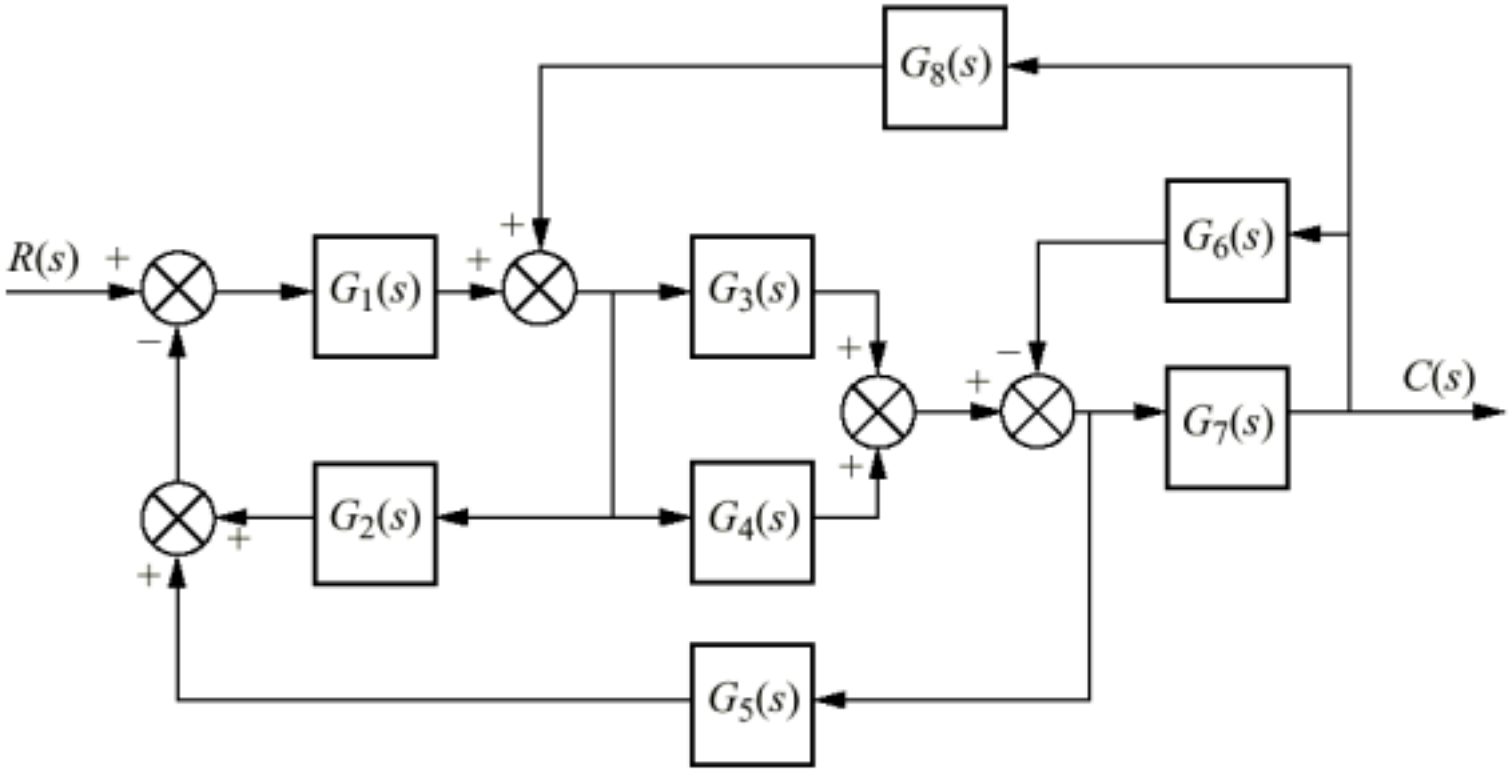


Figure P5.6

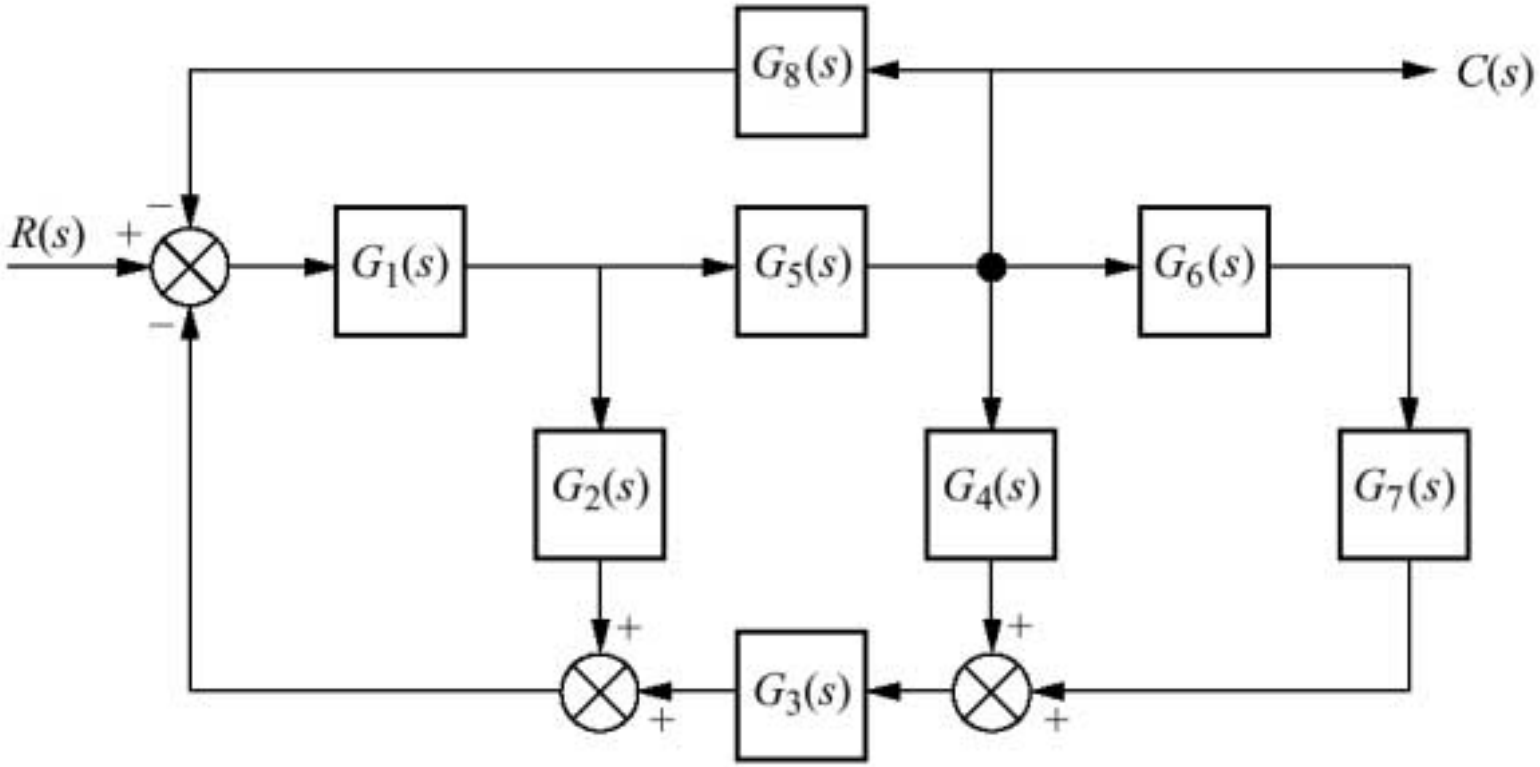


Figure P5.7

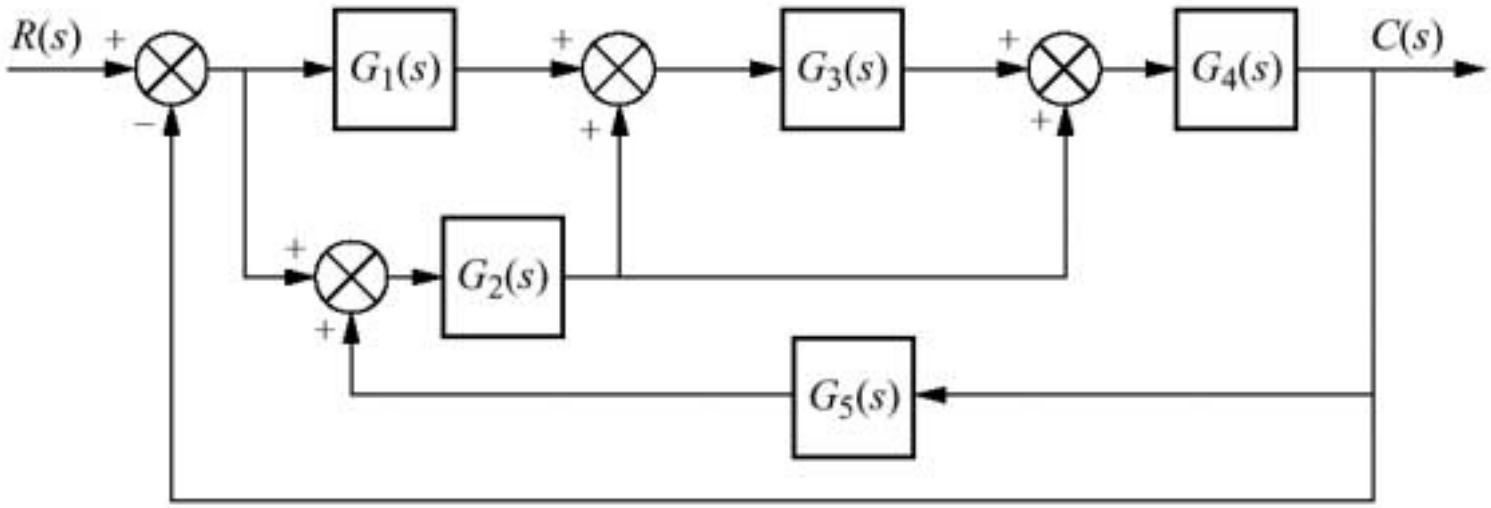


Figure P5.8

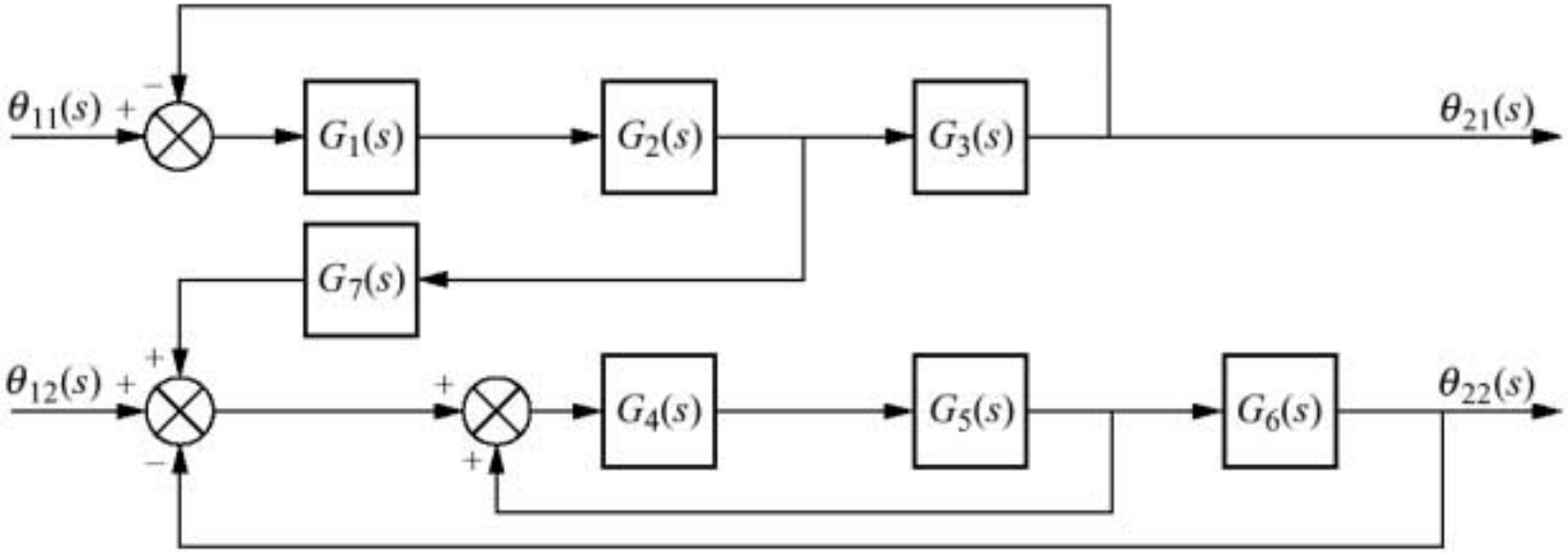


Figure P5.9

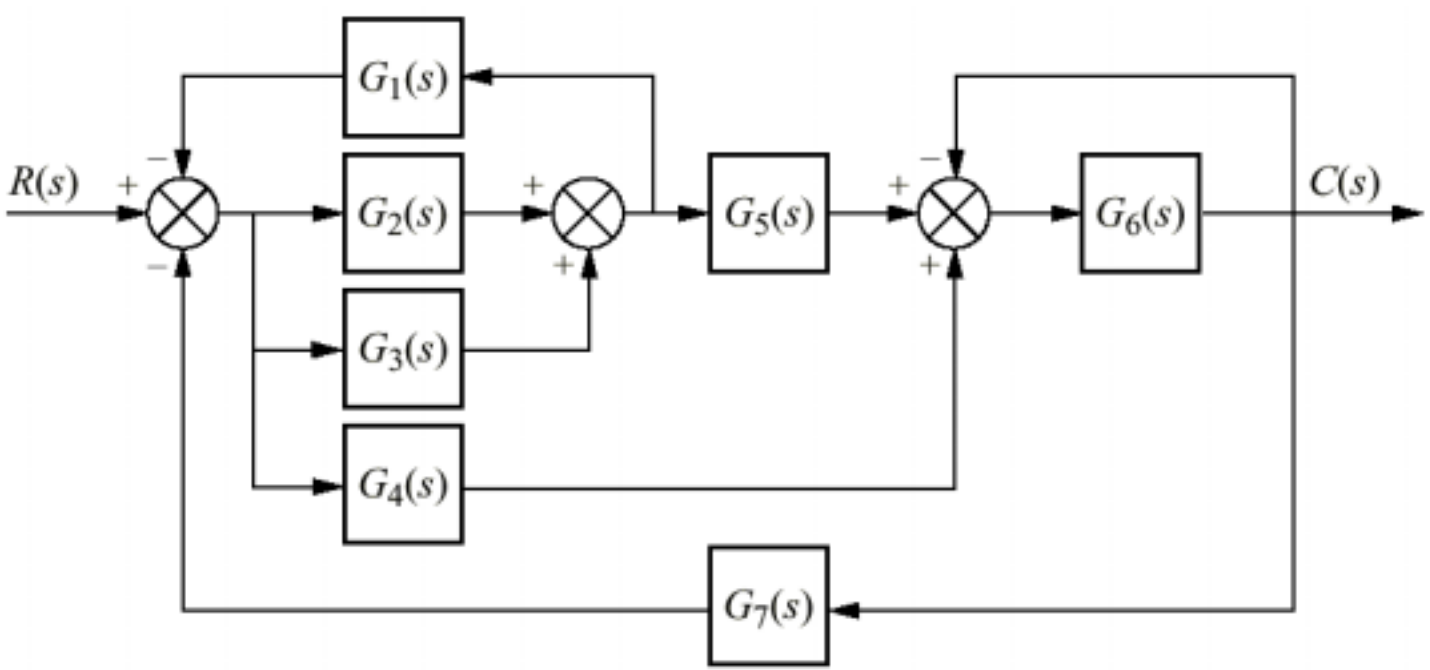


Figure P5.10

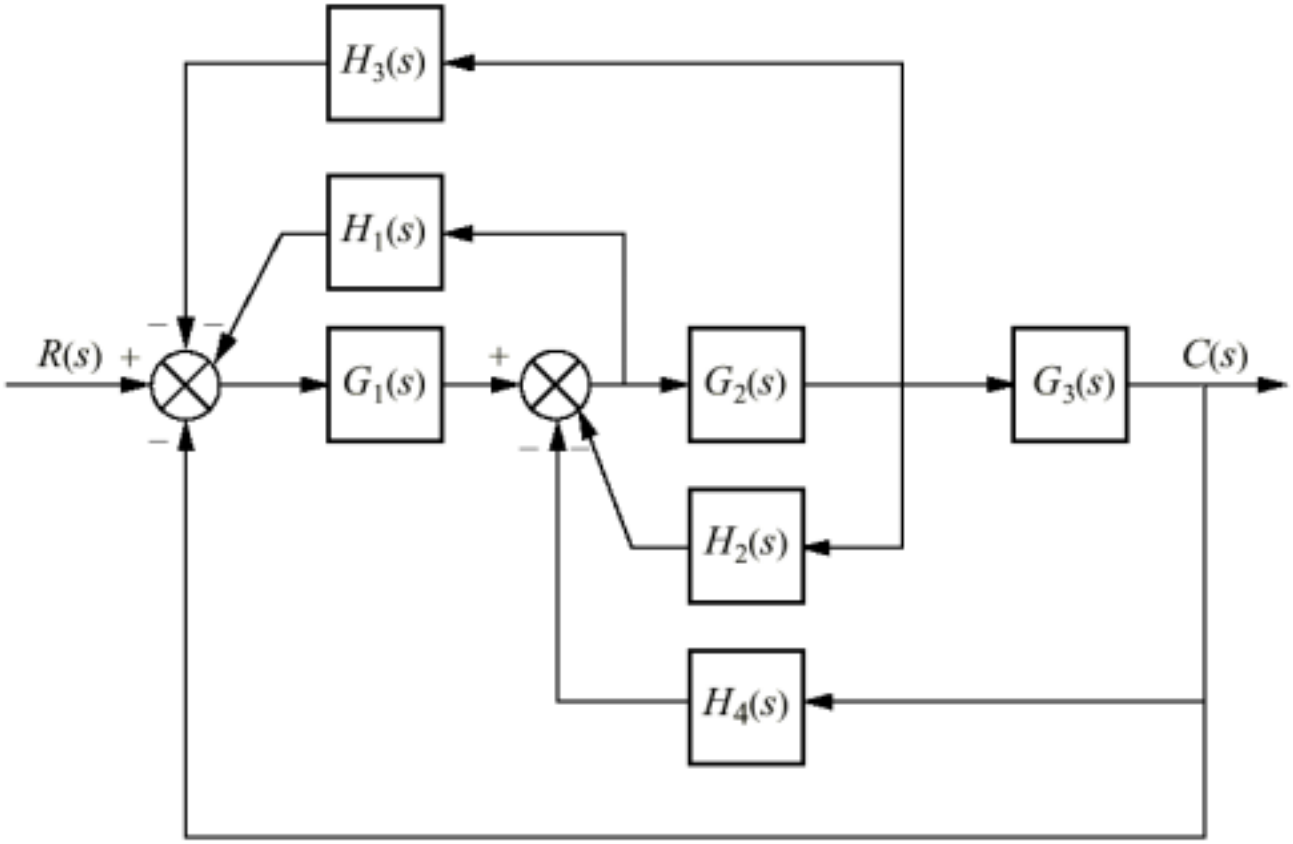


Figure P5.11

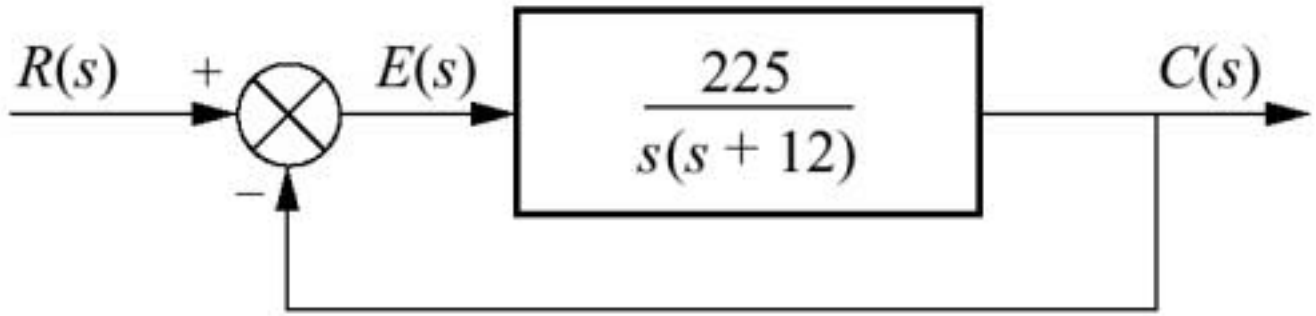


Figure P5.12

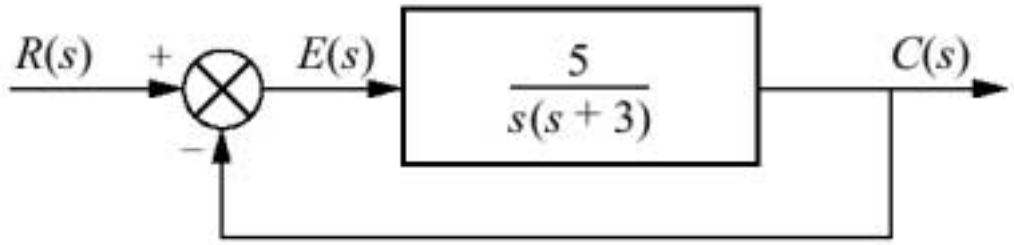


Figure P5.13

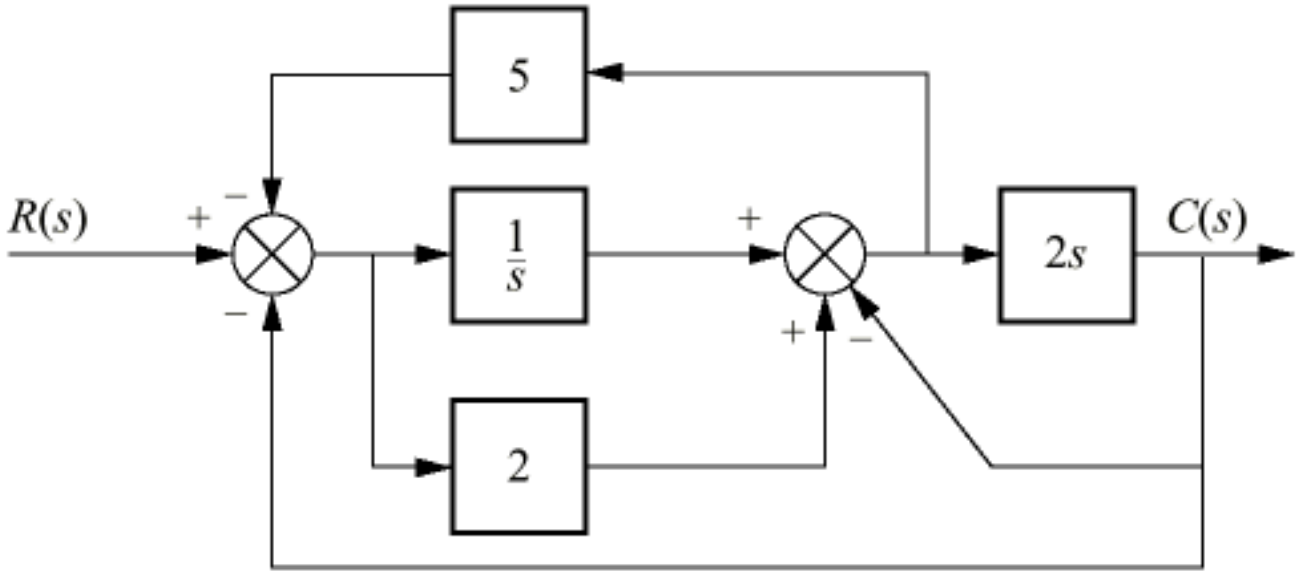


Figure P5.14

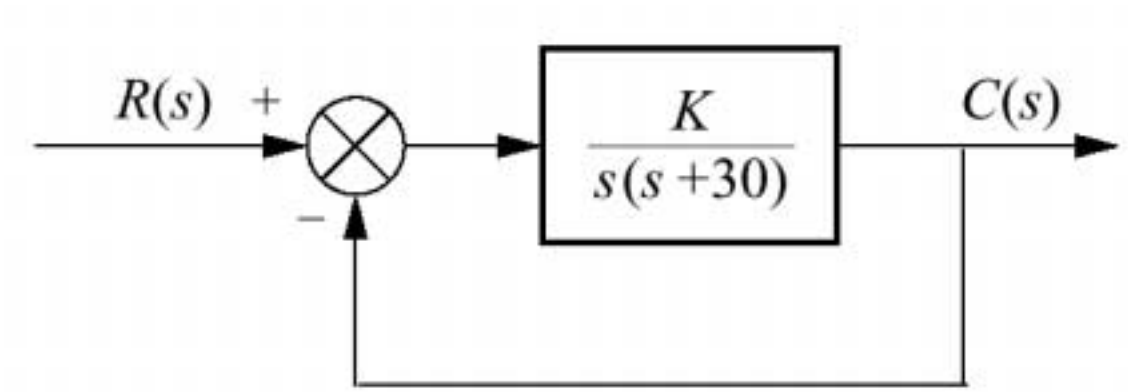


Figure P5.15

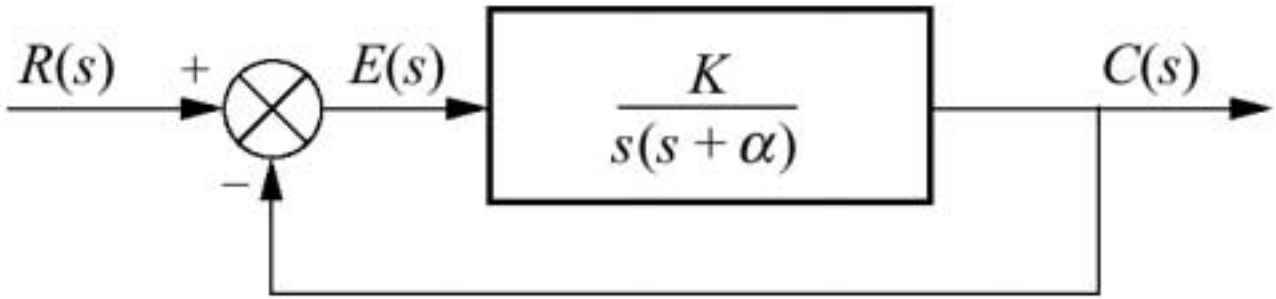


Figure P5.16

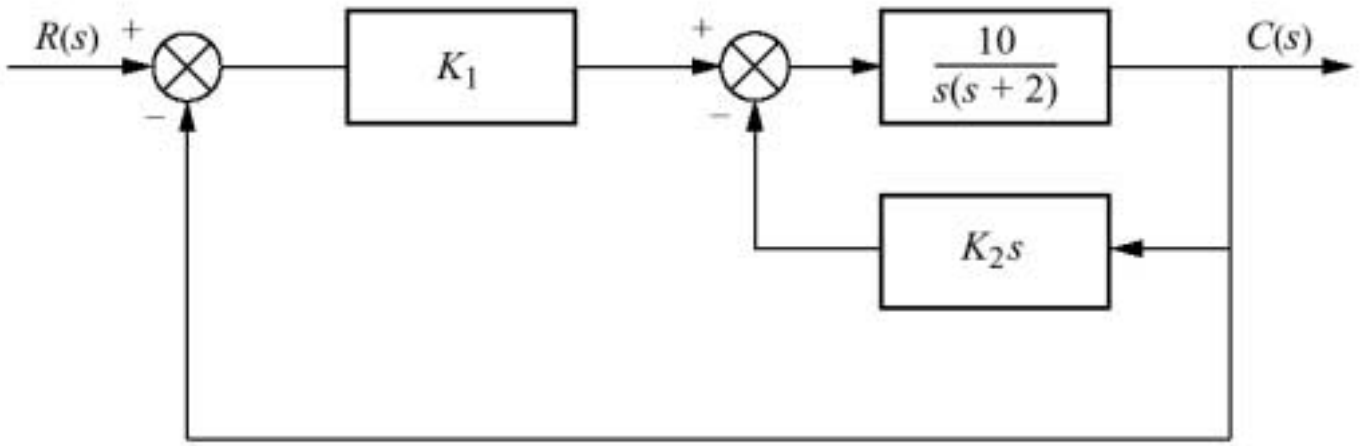


Figure P5.17

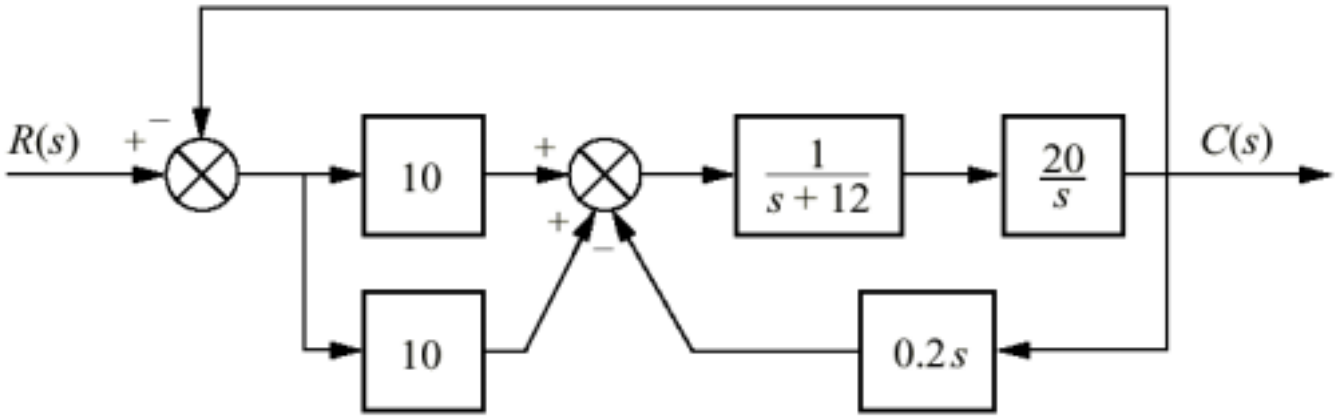


Figure P5.18

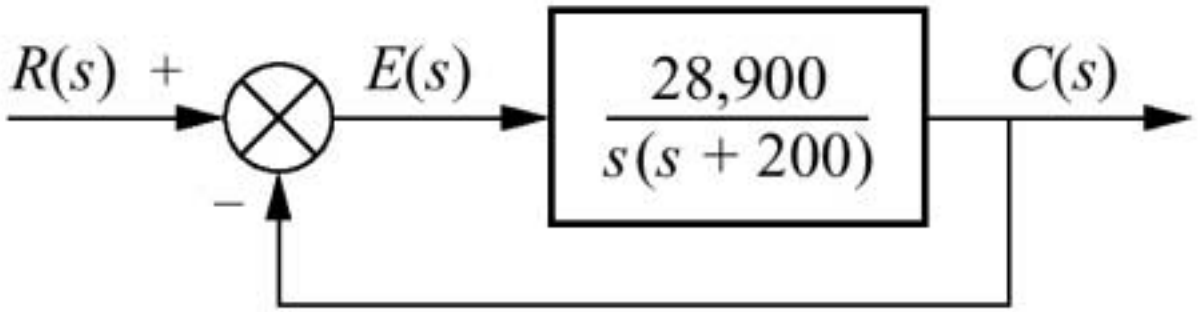


Figure P5.19

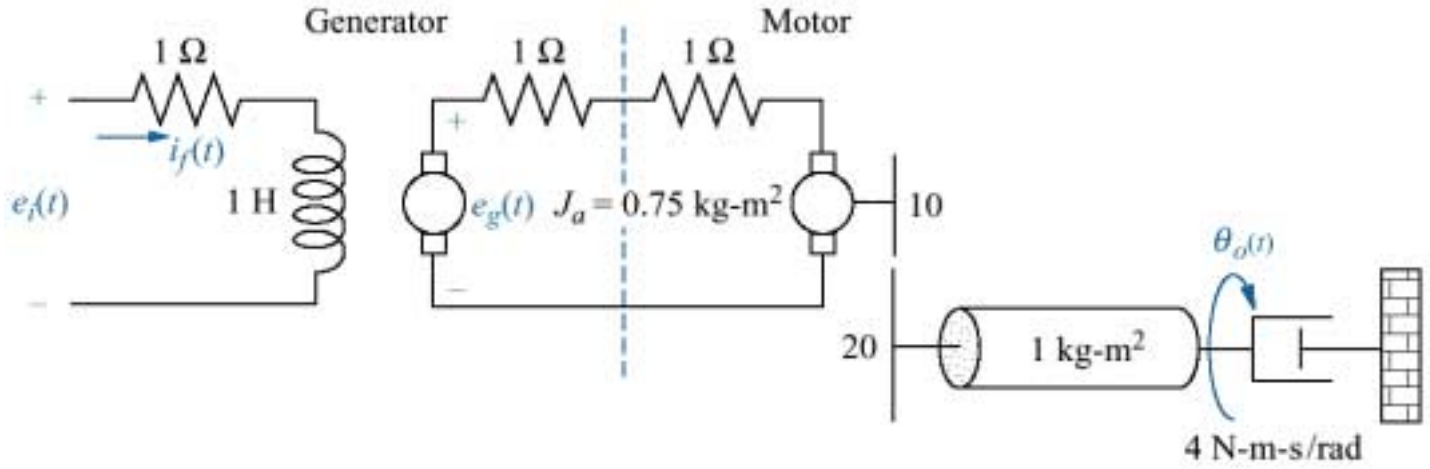


Figure P5.20

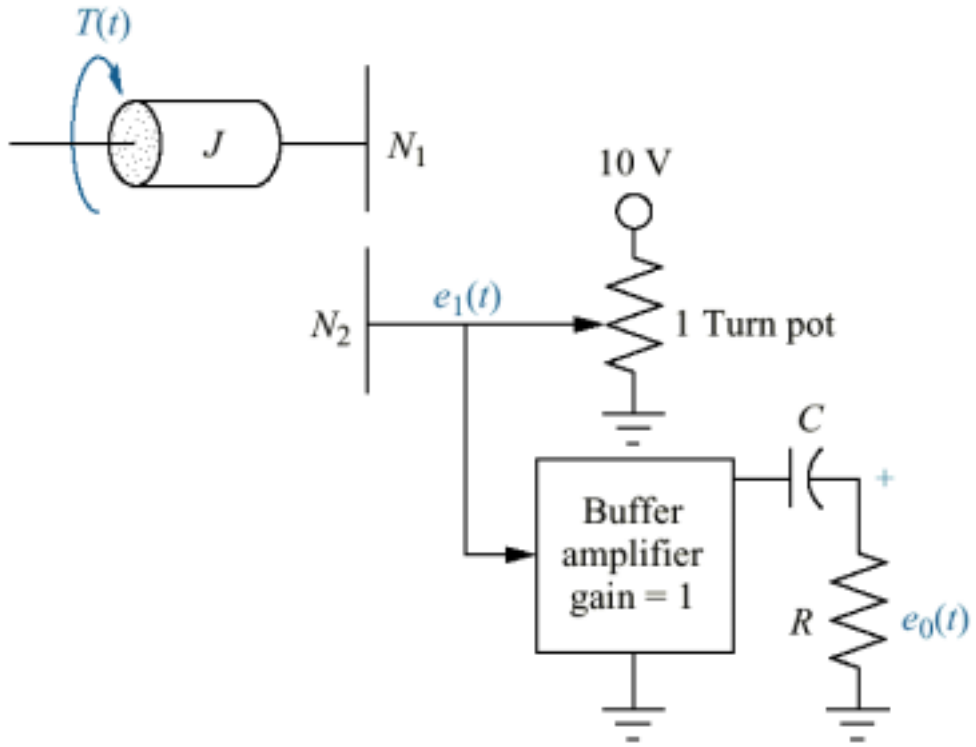


Figure P5.21

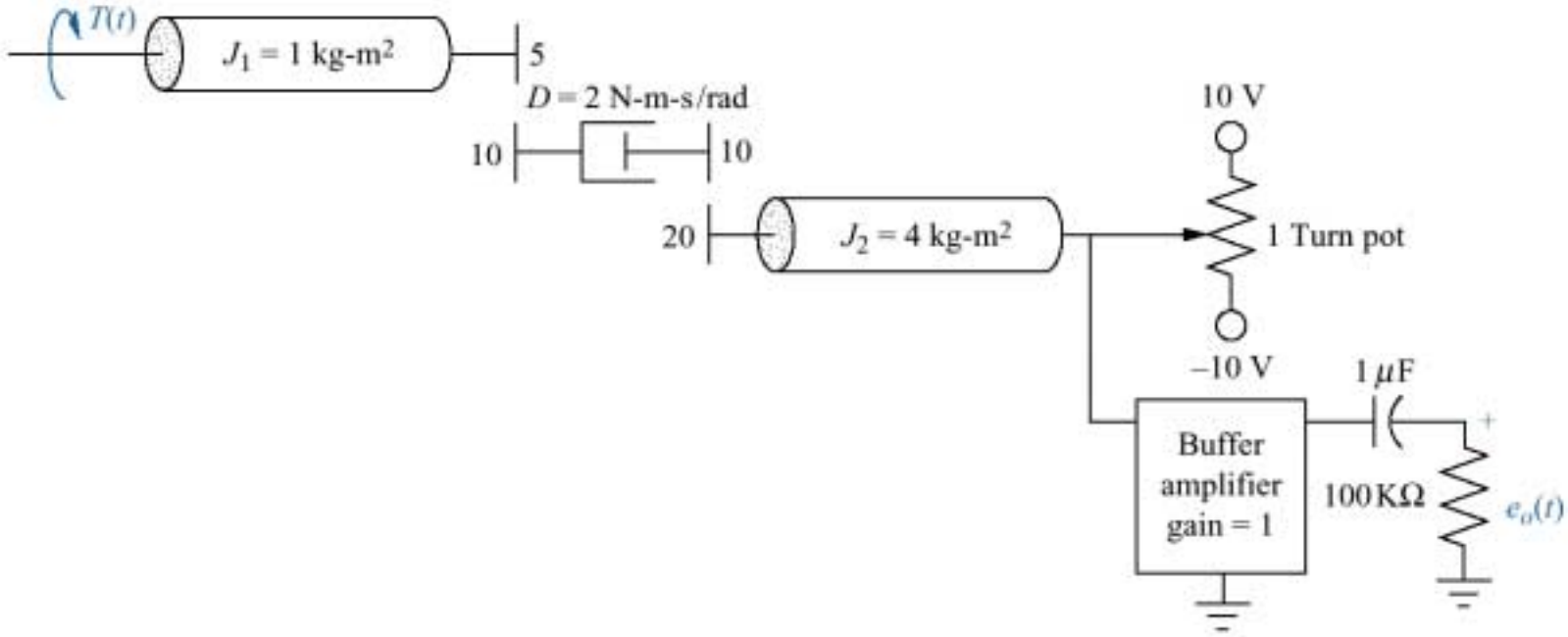


Figure P5.22

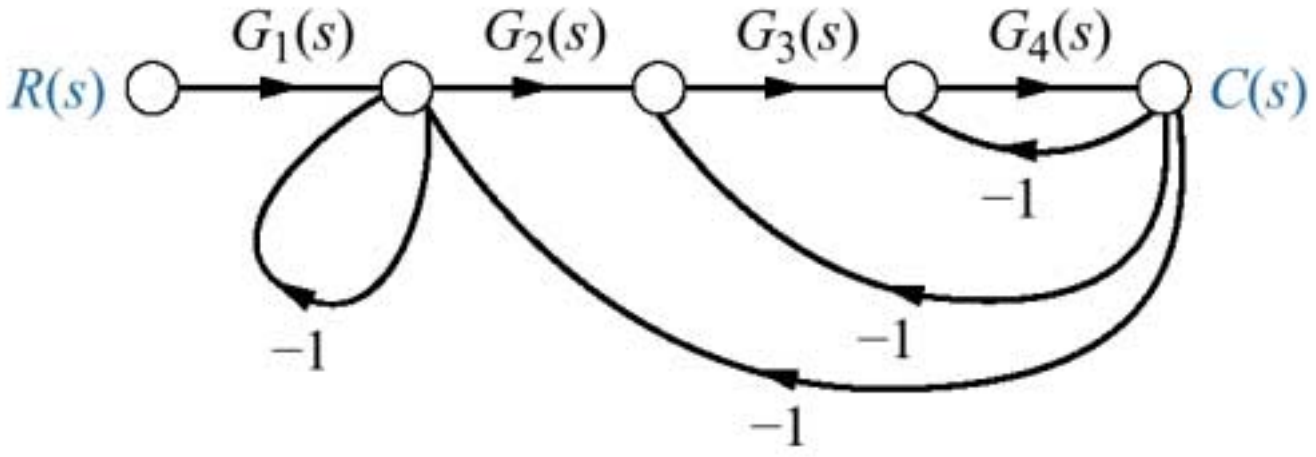


Figure P5.23

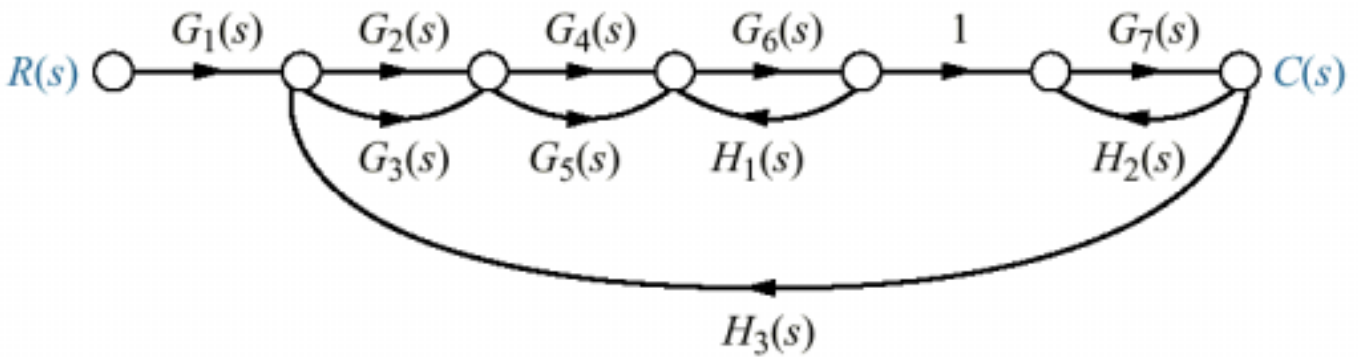
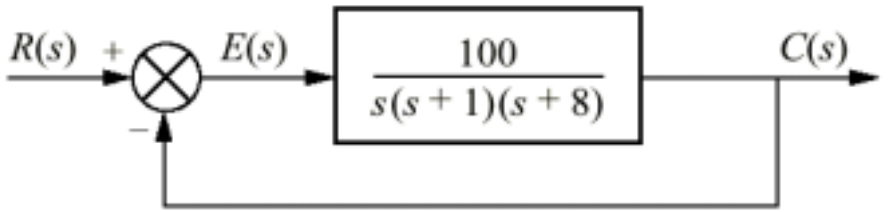
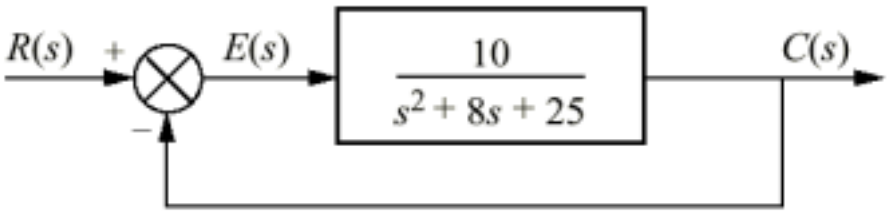


Figure P5.24
(*figure continues*)

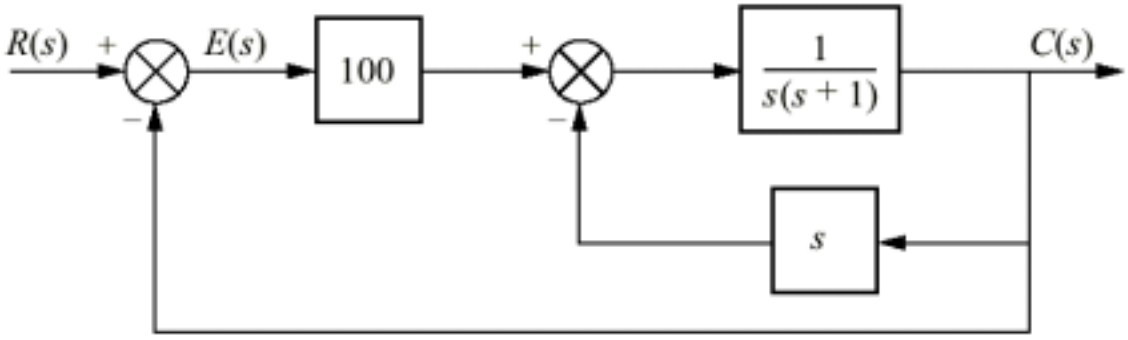


(*a*)

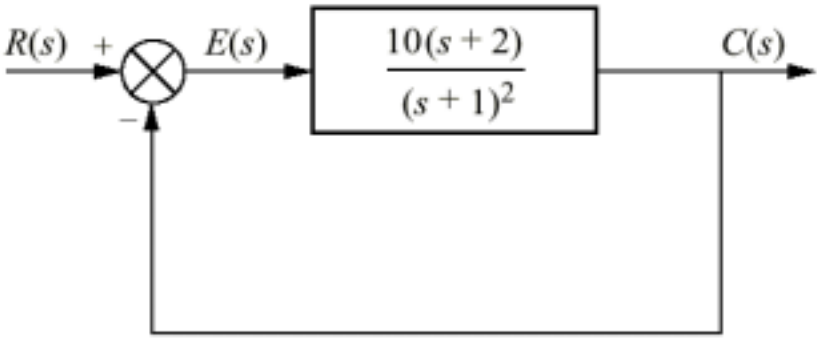


(*b*)

Figure P5.24 (*continued*)



(*c*)



(*d*)

Figure P5.25

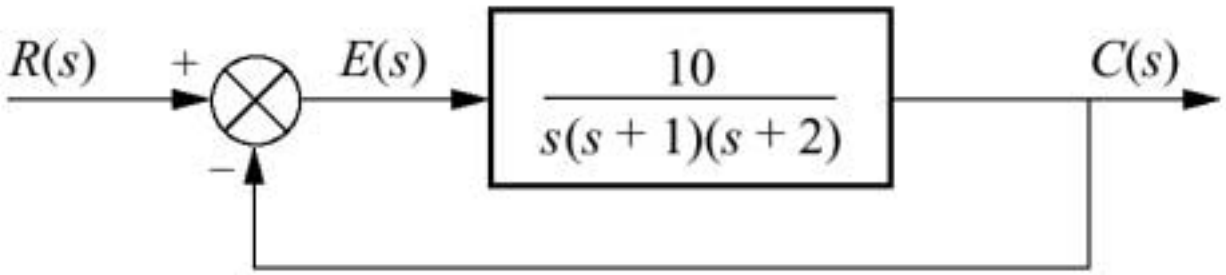


Figure P5.26

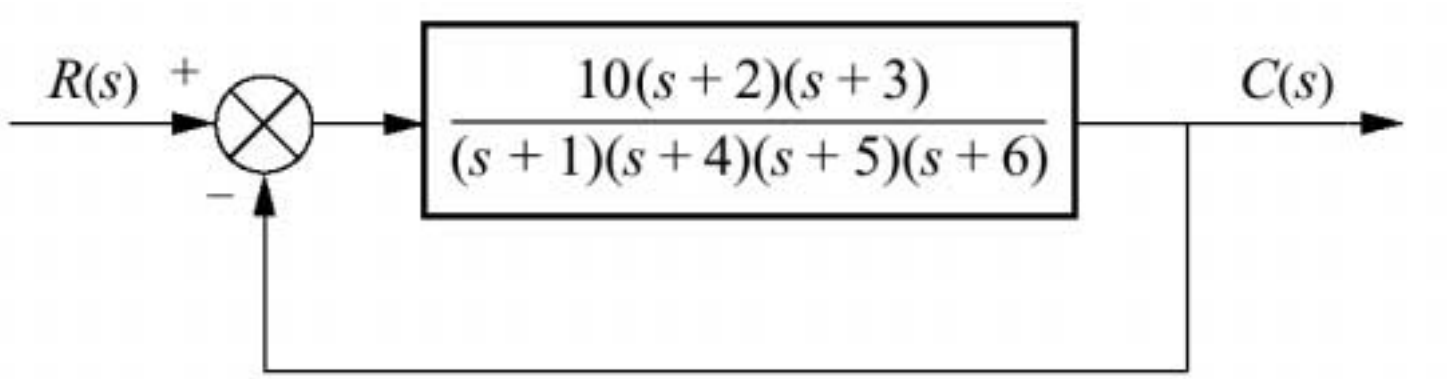


Figure P5.27

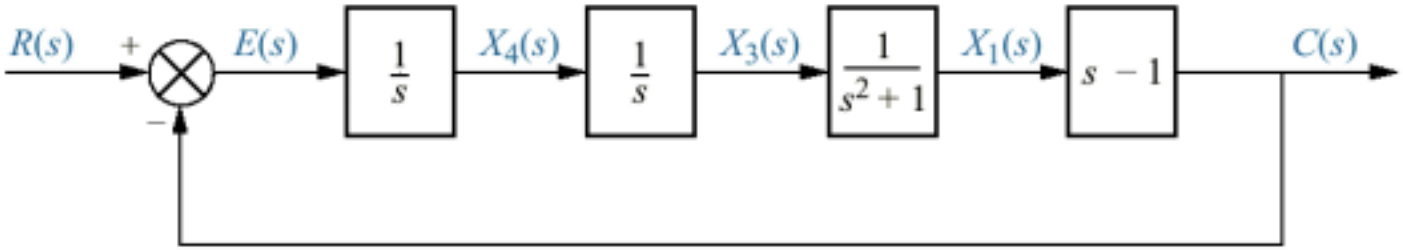


Figure P5.28

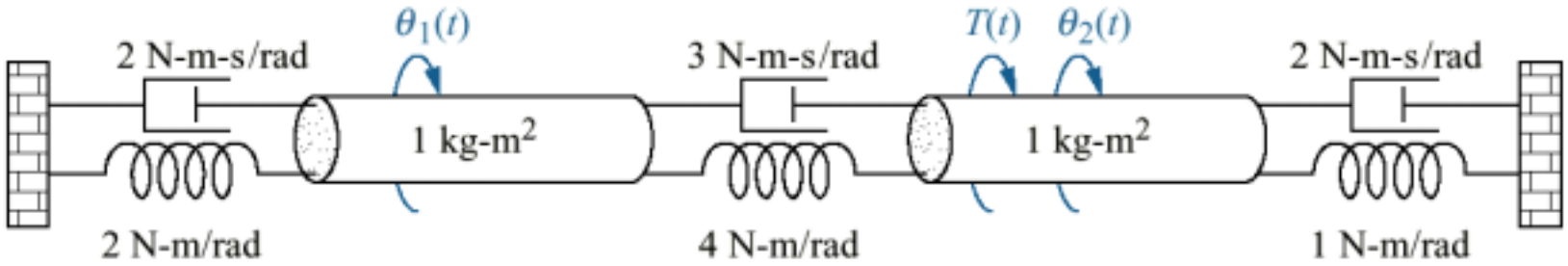


Figure P5.29

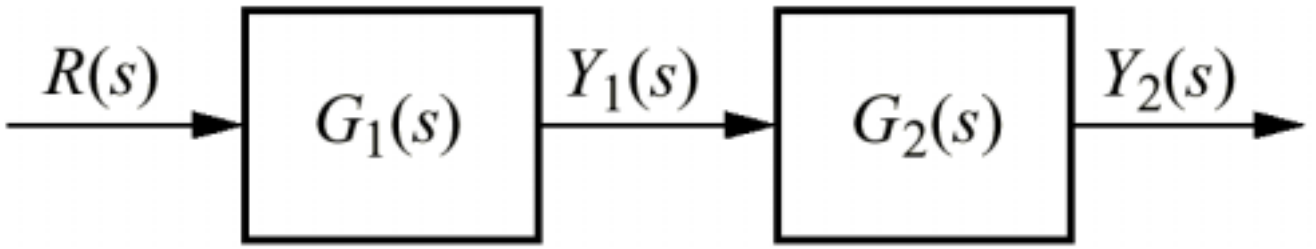


Figure P5.30

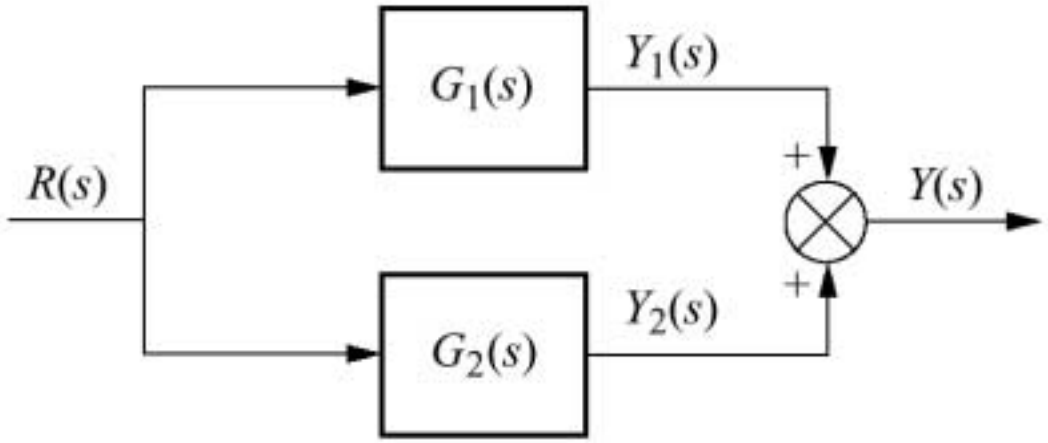


Figure P5.31

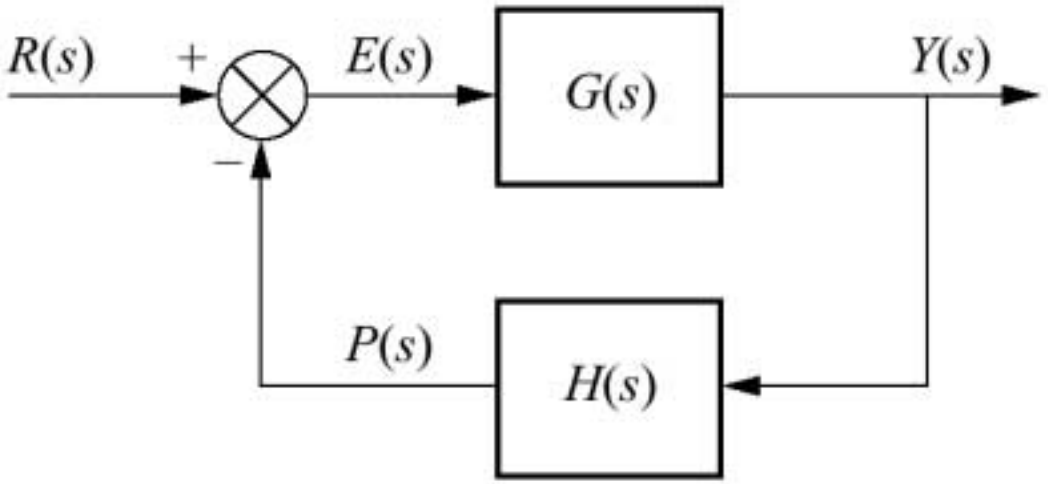


Figure P5.32
Space shuttle pitch control system (simplified)

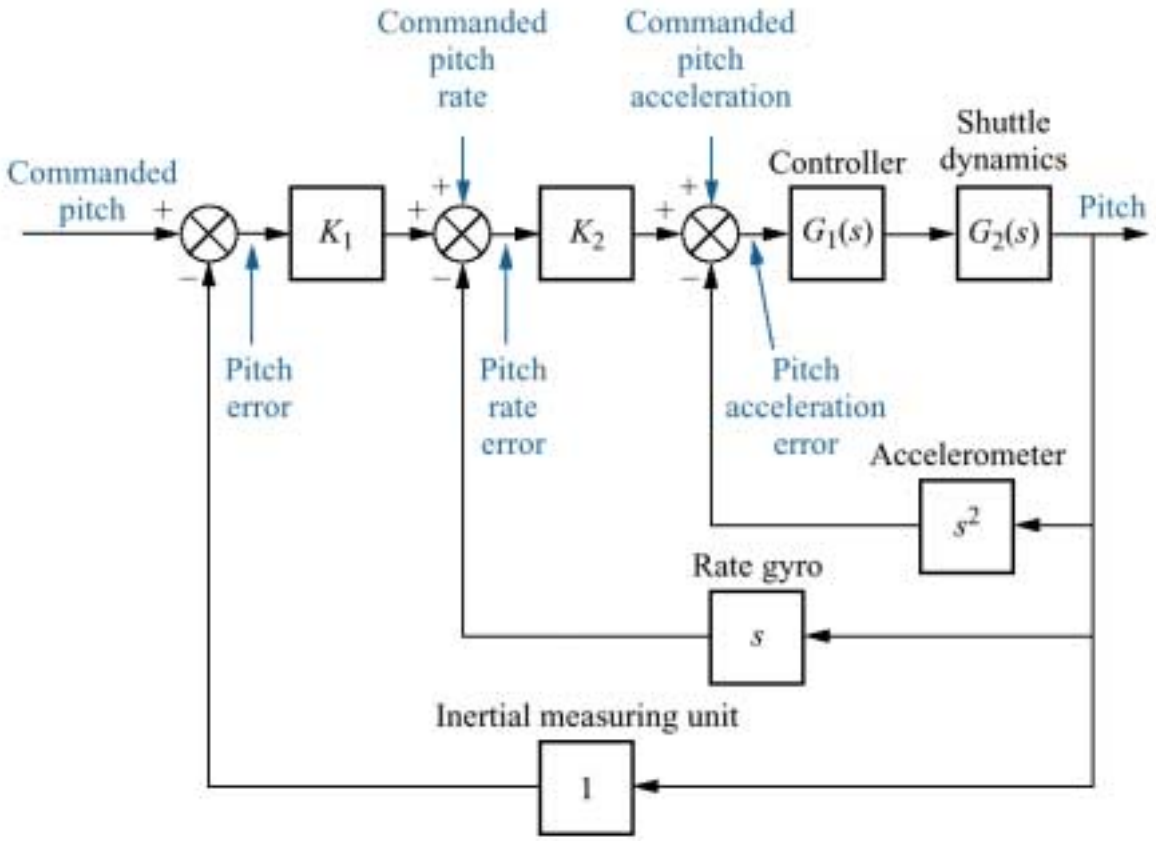


Figure P5.33
AM modulator

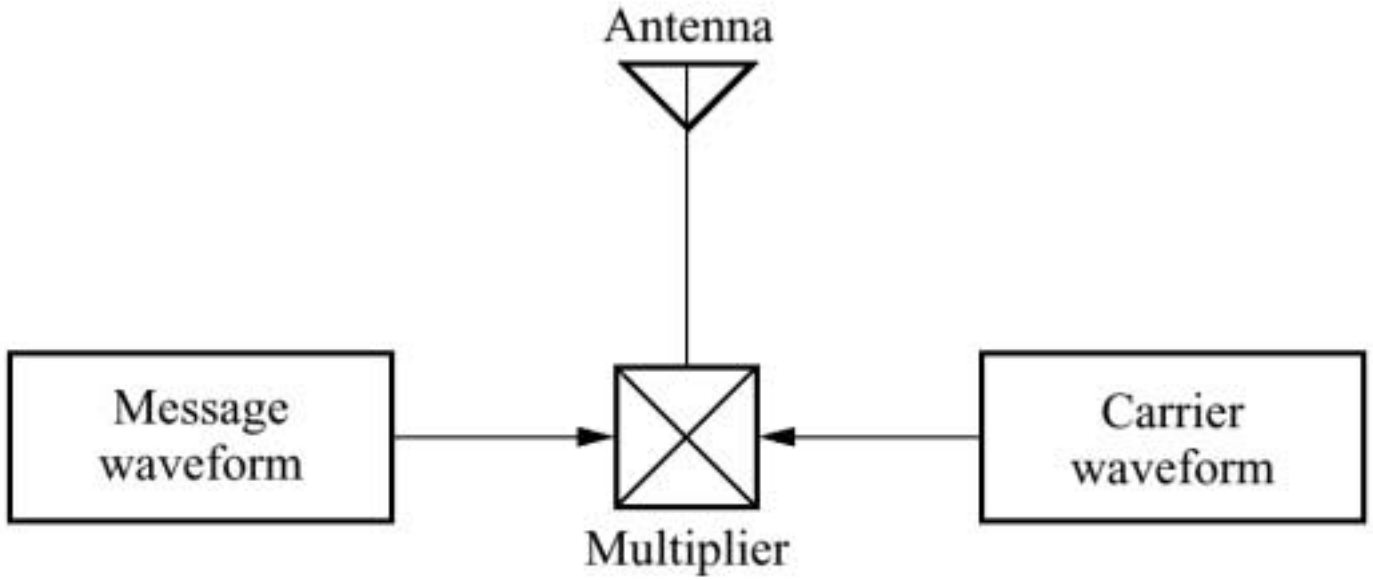


Figure P5.34
Feedback control system representing human eye movement

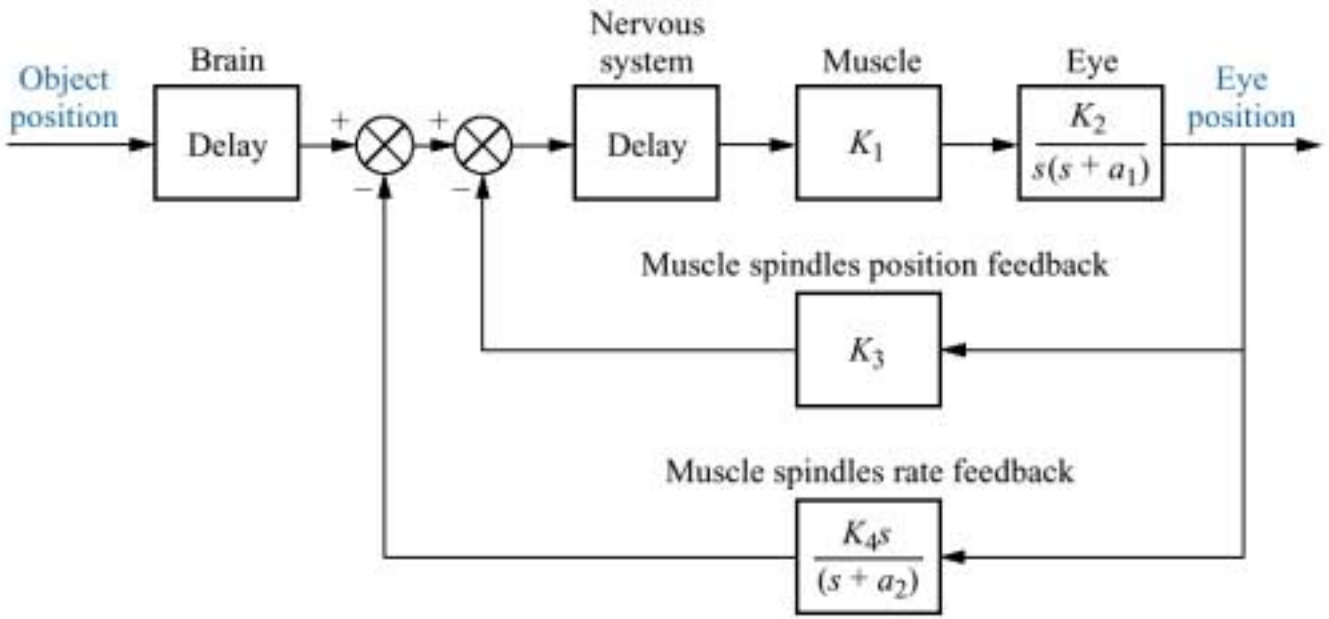
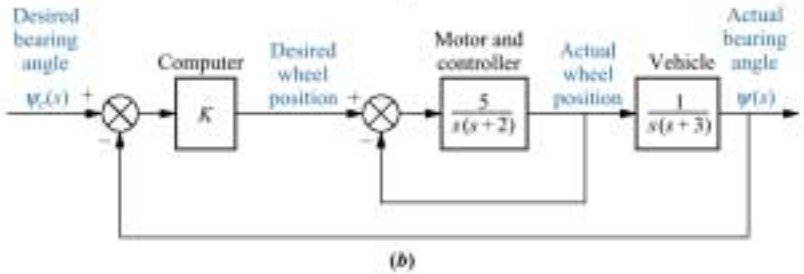


Figure P5.35
a. HelpMate robot used for in-hospital deliveries;
b. simplified block diagram for bearing angle control

(a)



(b)

Figure P5.36
a. Load tester (© 1992 IEEE)
b. approximate block diagram

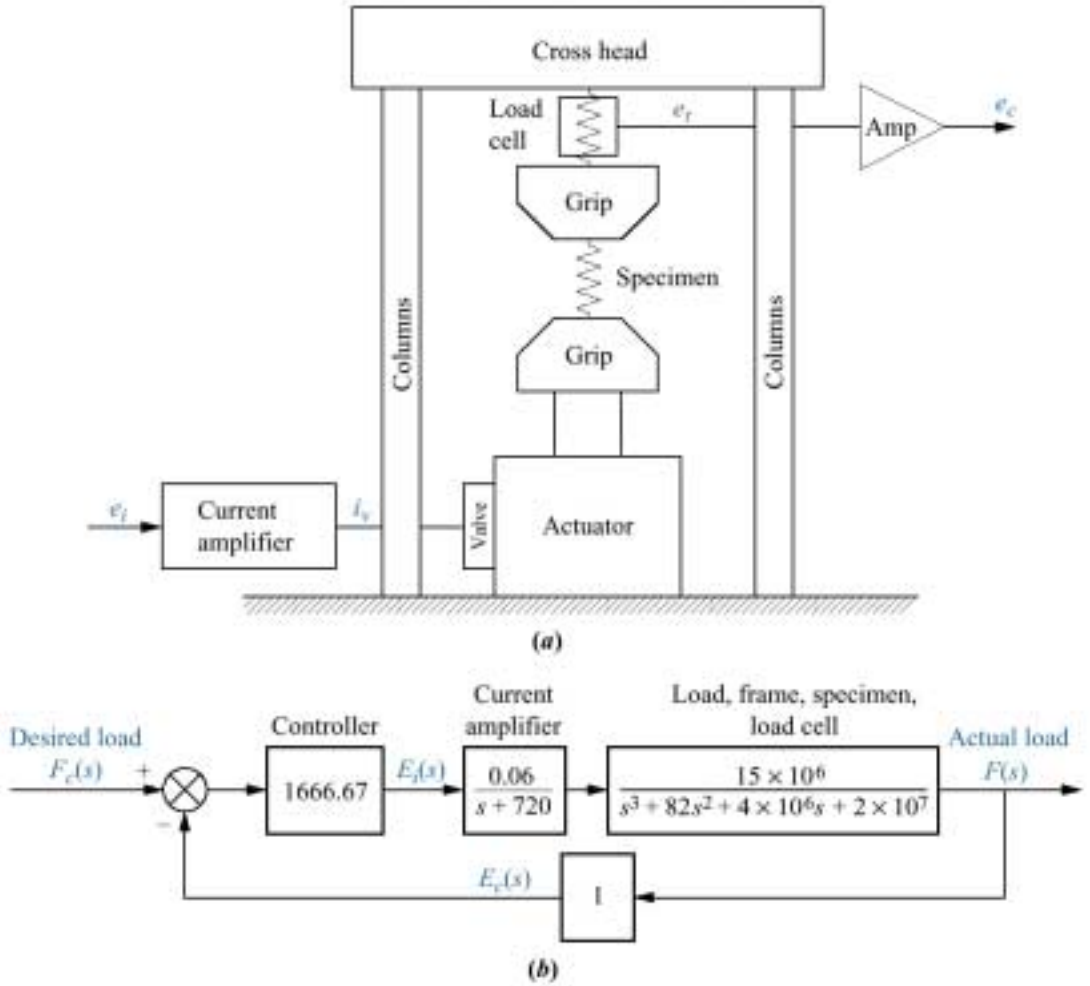


Figure P5.37
Solenoid coil circuit

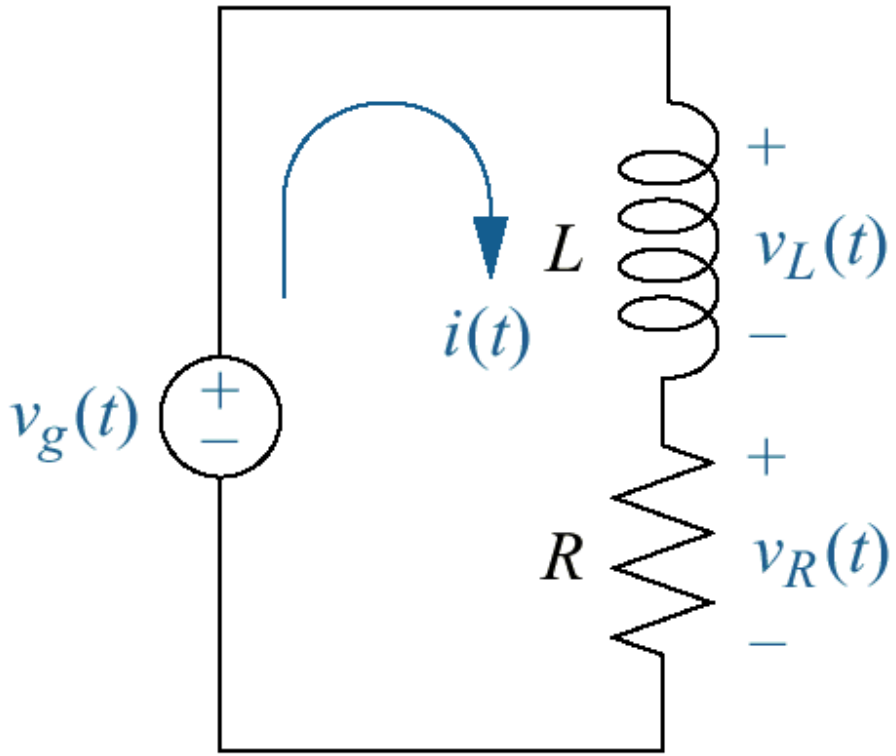


Figure P5.38
a. Position control: motor and load;
b. block diagram

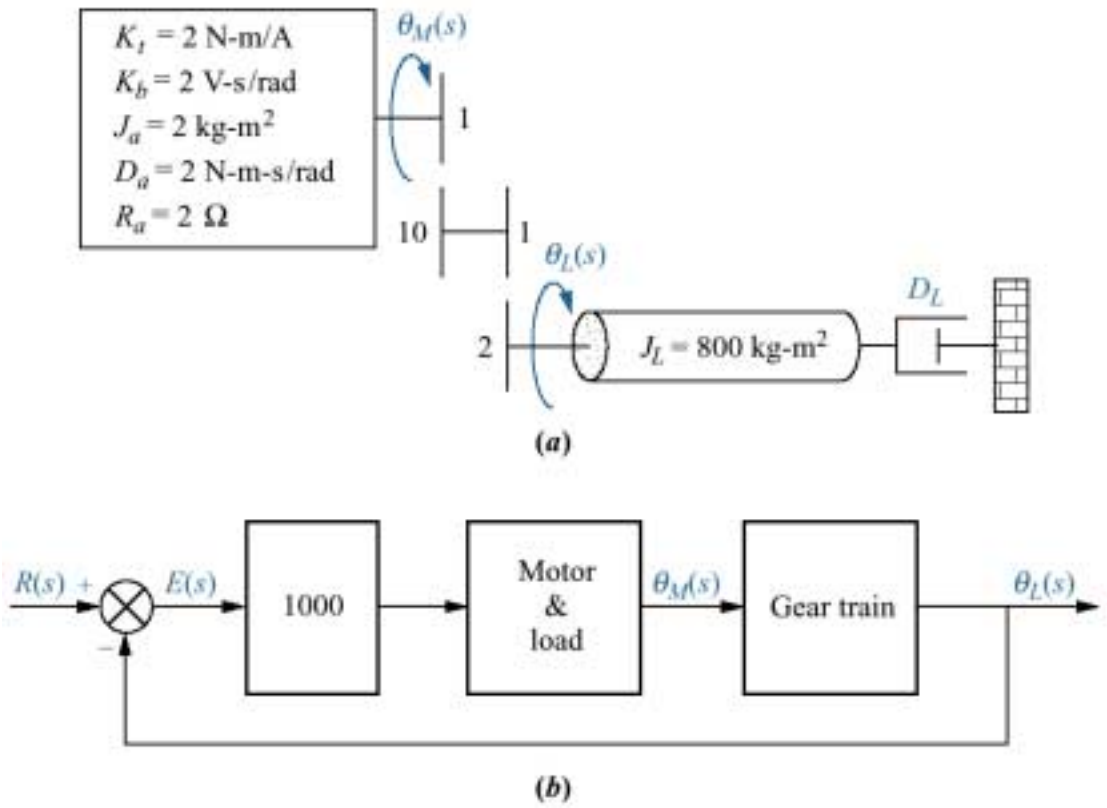


Figure P5.39
a. Position control;
b. position control with tachometer

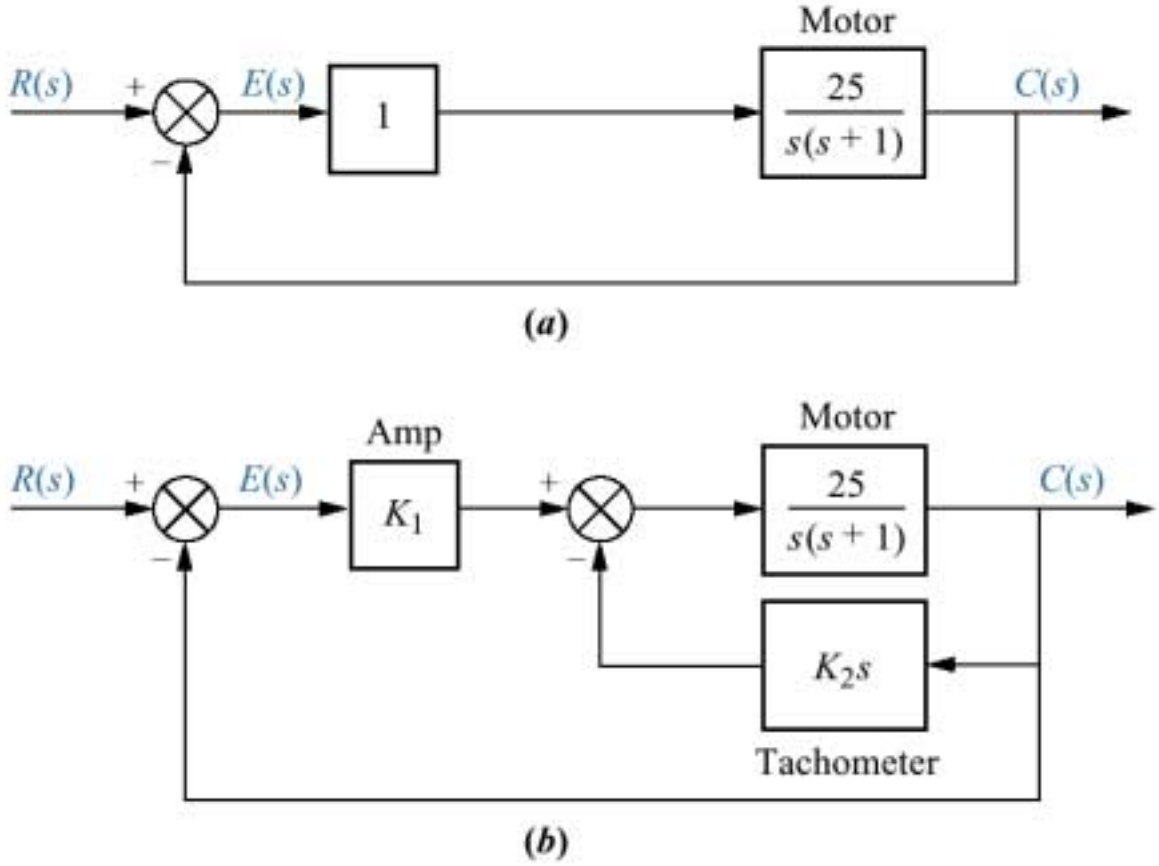


Figure P5.40
Position control

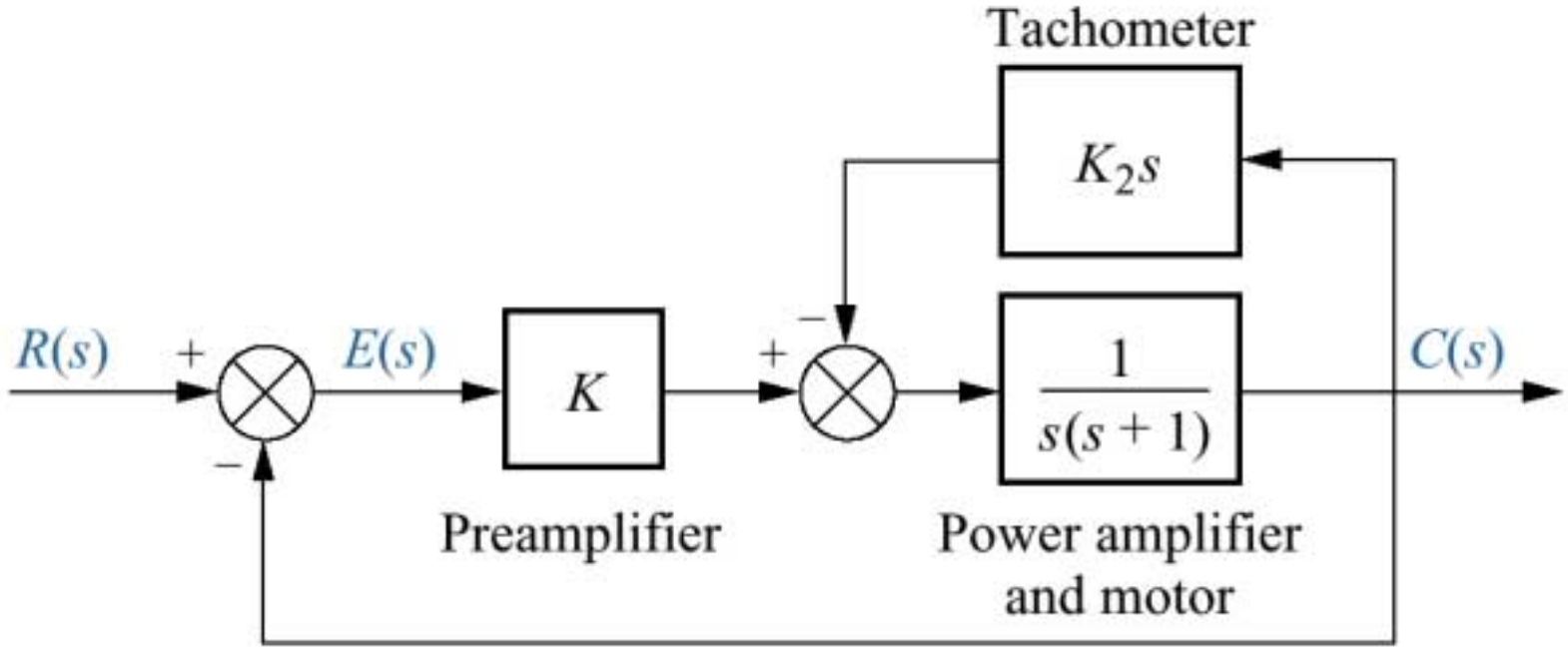


Figure P5.41
a. Motor and load;
b. Motor and load in feedback system