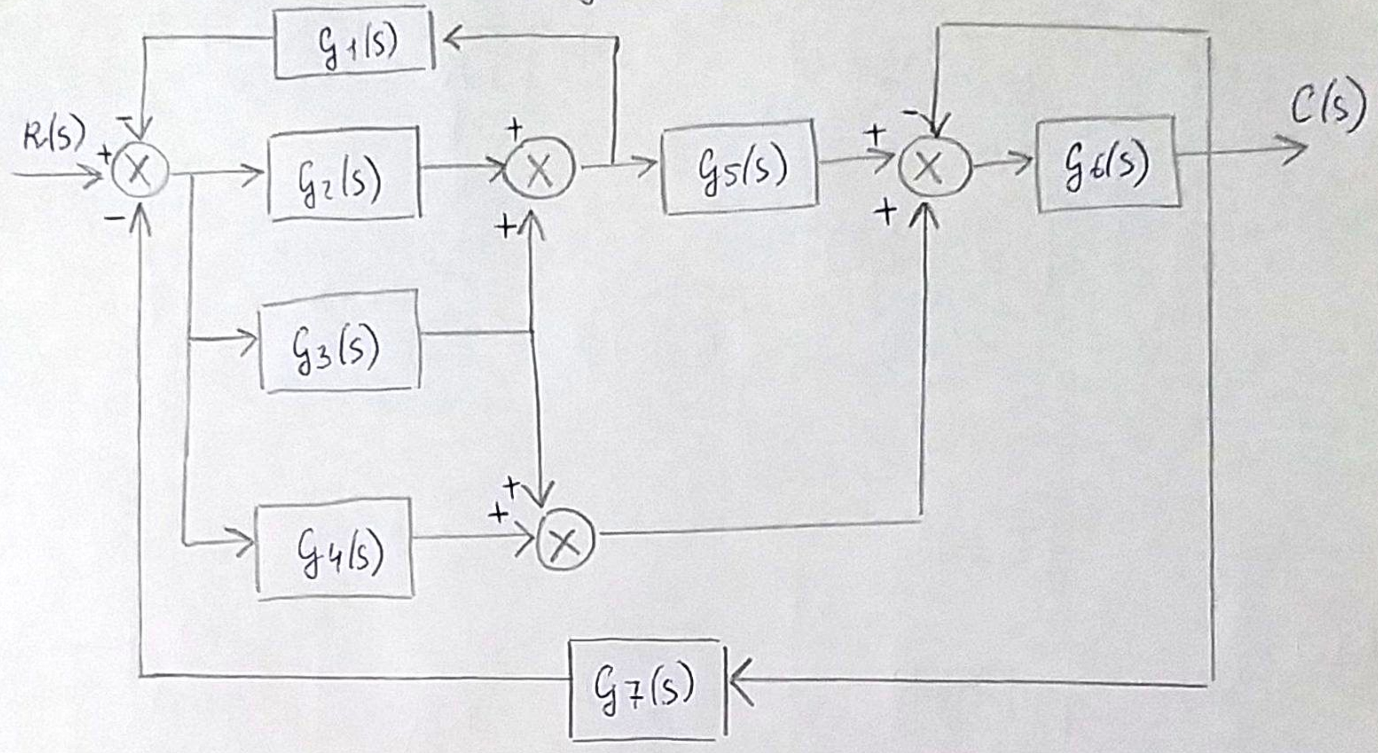
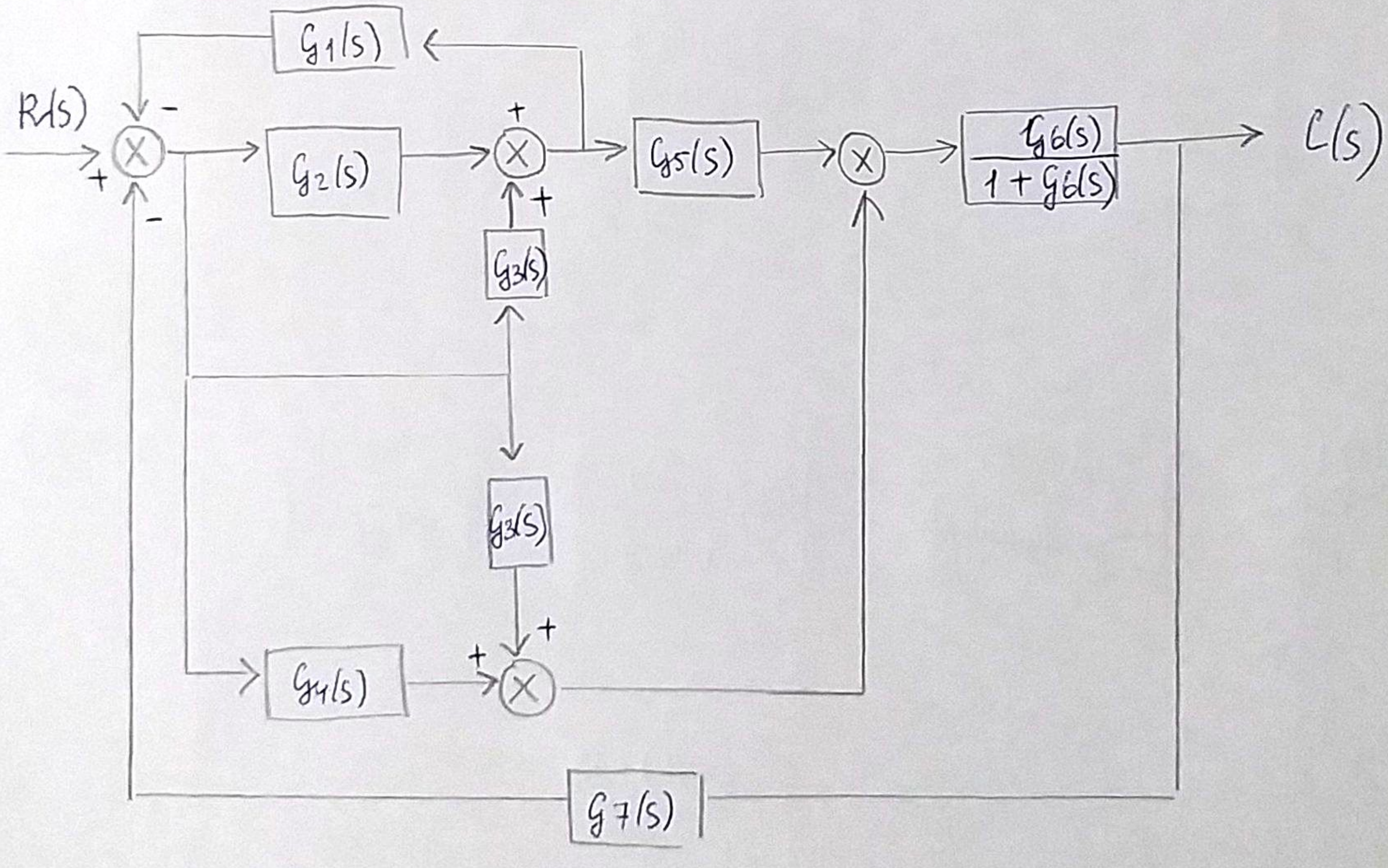
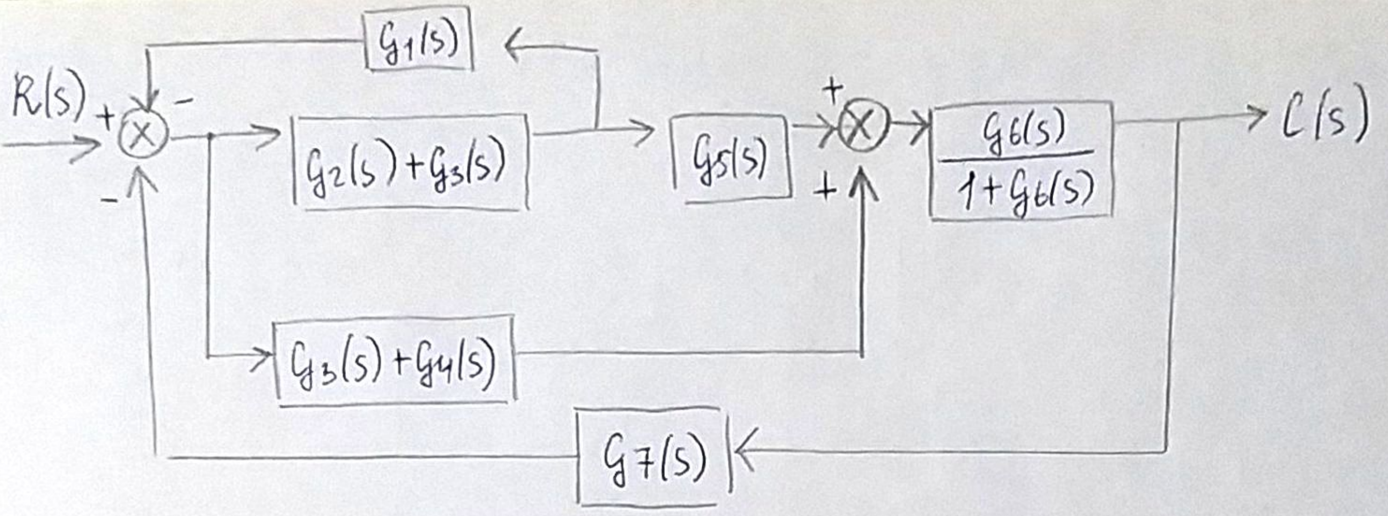
Robt 303 Zarema Balgabekova HW1

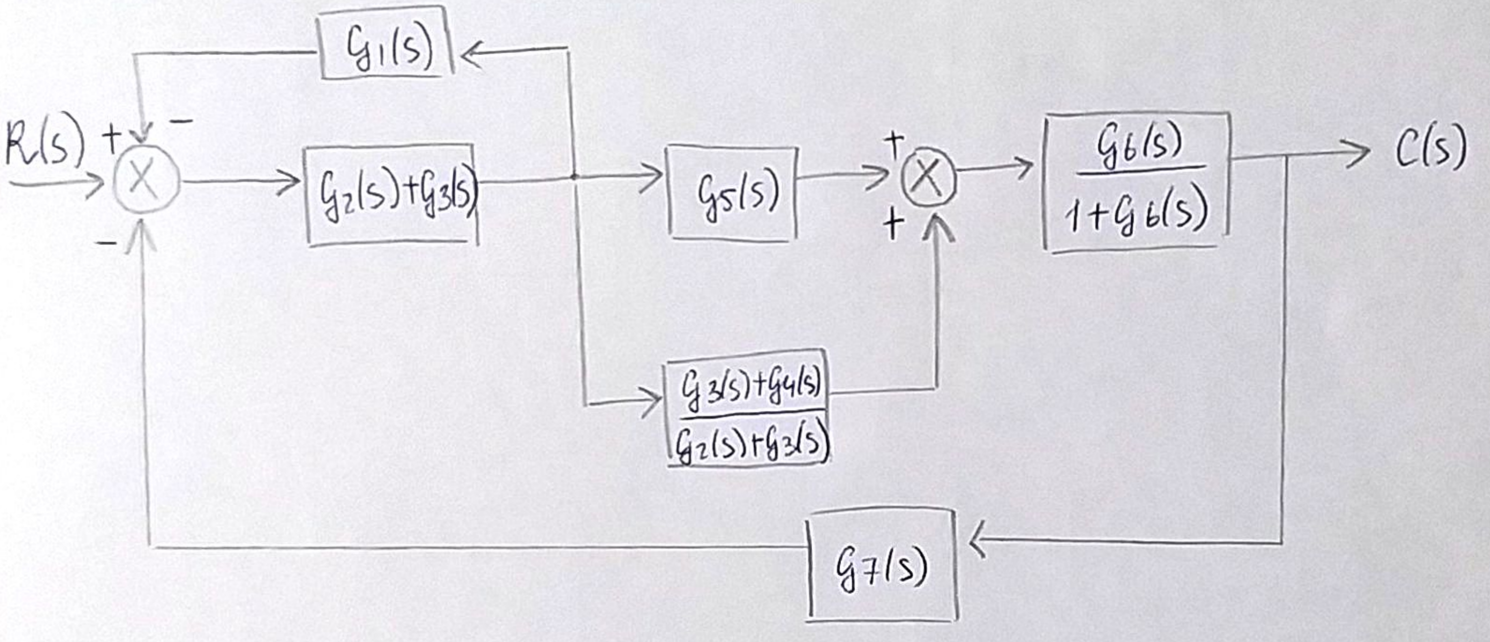
1. a)



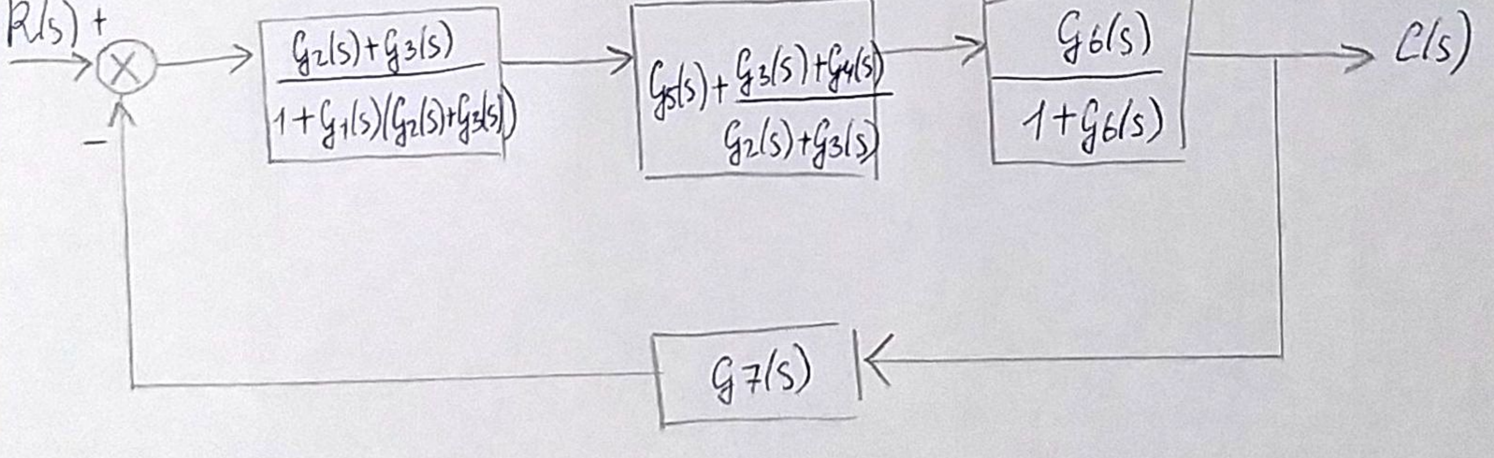




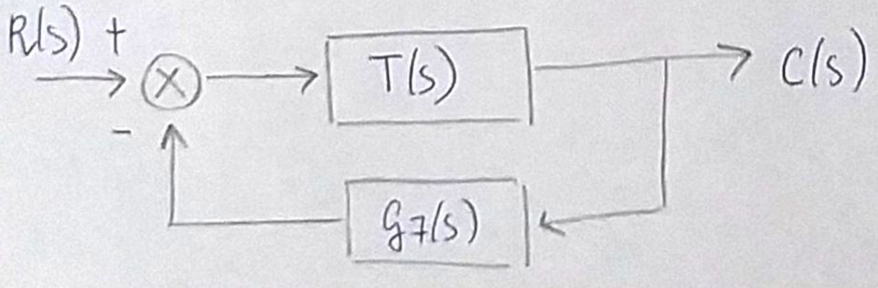
R(s)
G1(s)
G2(s)+G3(s)
G5(s)
G6(s) / 1+G6(s)
C(s)
G3(s)+G4(s)
G7(s)



R(s)
G1(s)
G2(s)+G3(s)
G5(s)
G6(s) / 1+G6(s)
C(s)
G3(s)+G4(s) / G2(s)+G3(s)
G7(s)



R(s)
G2(s)+G3(s) / 1+G1(s)(G2(s)+G3(s))
G5(s)+ G3(s)+G4(s) / G2(s)+G3(s)
G6(s) / 1+G6(s)
C(s)
G7(s)



R(s)
T(s)
C(s)
G7(s)

$$T(s) = \frac{\cancel{(G_2(s)+G_3(s))}\cdot(G_3(s)+G_4(s)+G_2(s)G_5(s)+G_3(s)G_5(s))\cdot G_6(s)}{(1+G_1(s)G_2(s)+G_1(s)G_3(s))\,\cancel{(G_2(s)+G_3(s))}\cdot(1+G_6(s))} =$$

$$\frac{G_6(s)\cdot(G_3(s)+G_4(s)+G_2(s)G_5(s)+G_3(s)G_5(s))}{(1+G_6(s))(1+G_1(s)G_2(s)+G_1(s)G_3(s))}$$

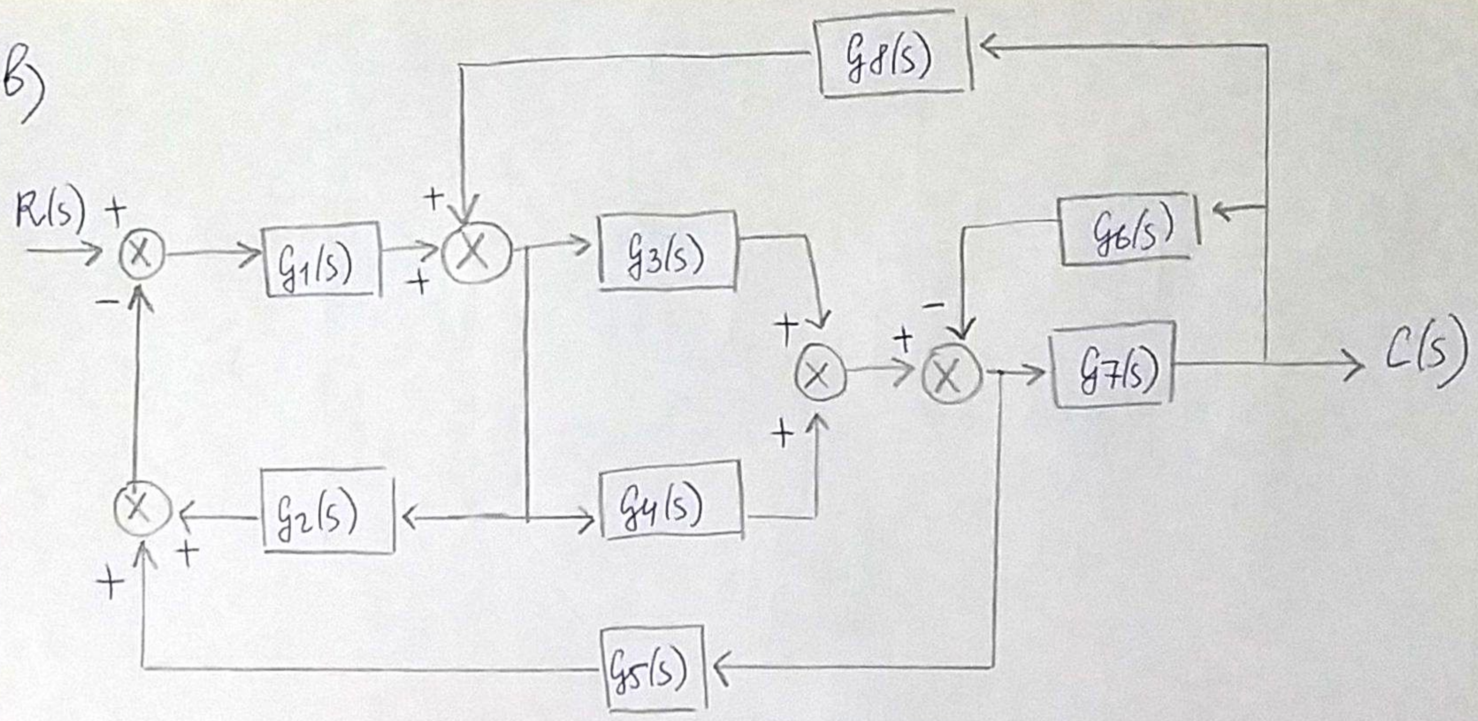
$$G(s) = \frac{C(s)}{R(s)} = \frac{T(s)}{1+G_7(s)T(s)} =$$

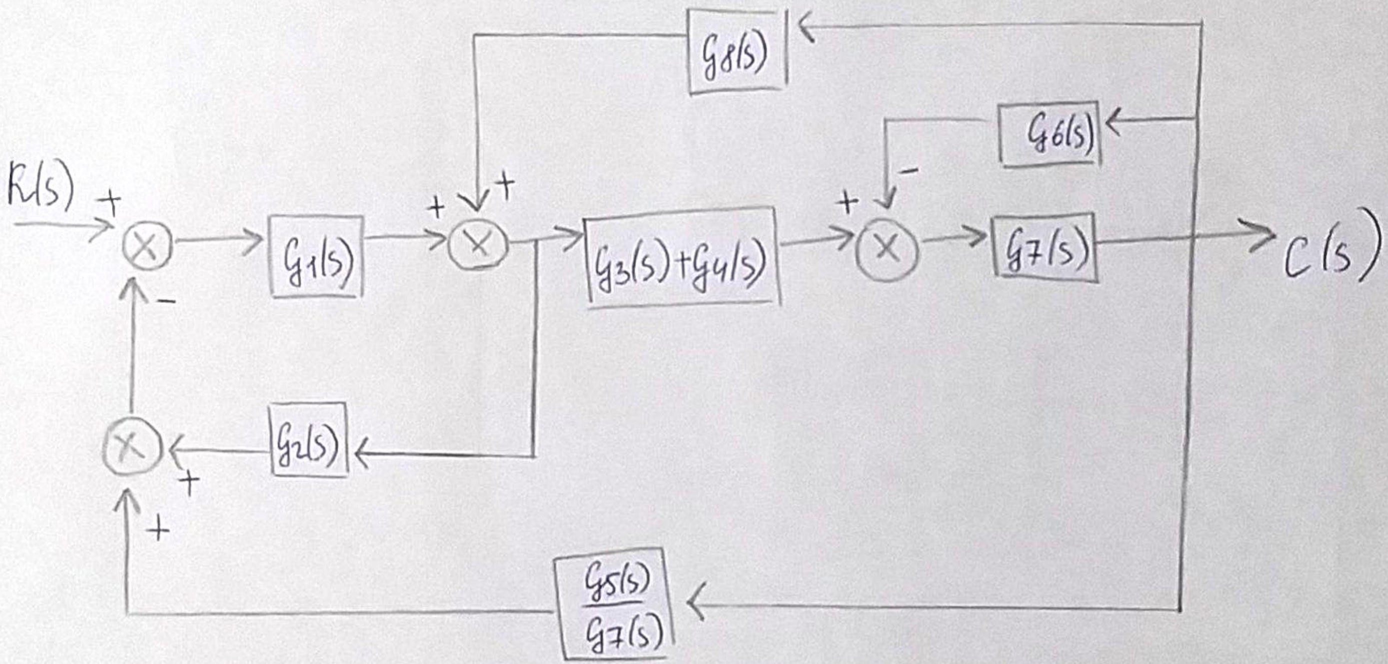
$$\frac{G_6(s)\cdot(G_3(s)+G_4(s)+G_2(s)G_5(s)+G_3(s)G_5(s))}{(1+G_6(s))(1+G_1(s)G_2(s)+G_1(s)G_3(s)) + G_6(s)G_7(s)(G_3(s)+G_4(s)+G_2(s)G_5(s)+G_3(s)G_5(s))}$$

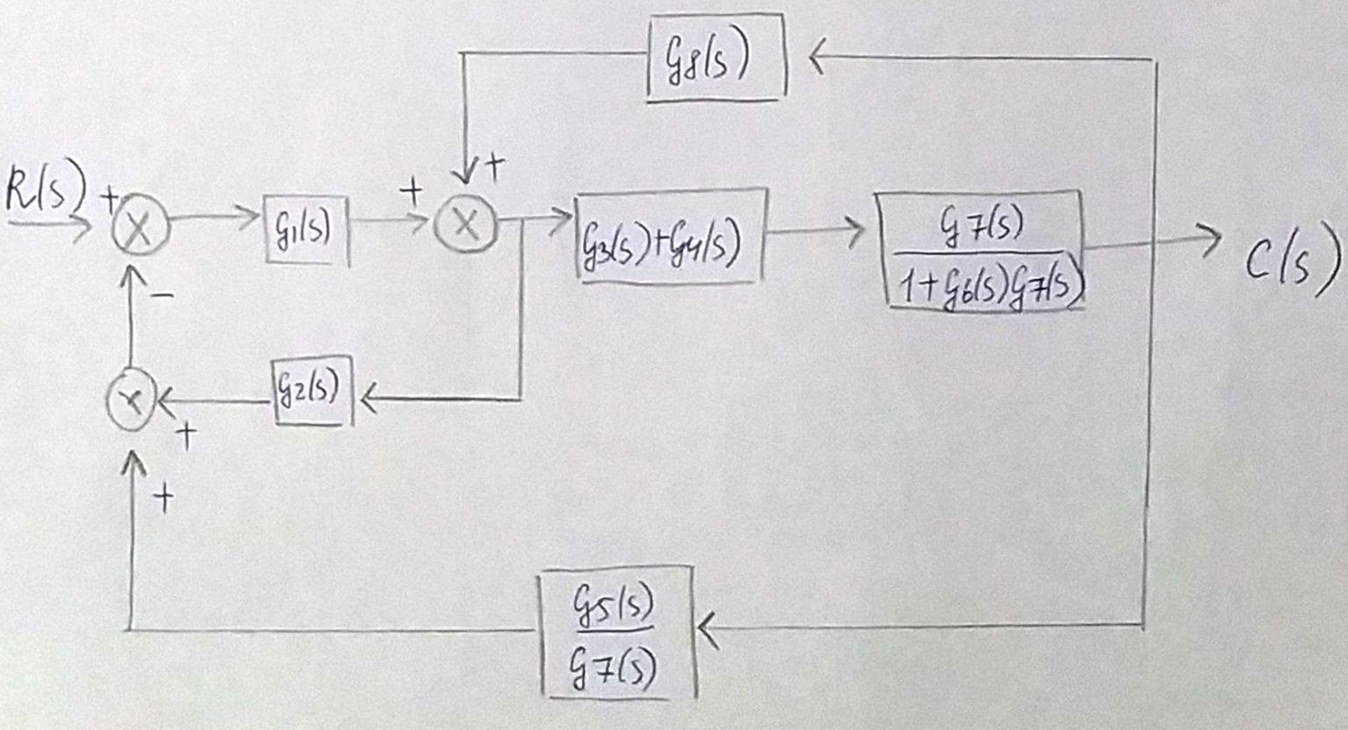
$$R(s) \rightarrow \boxed{G(s)} \rightarrow C(s)$$

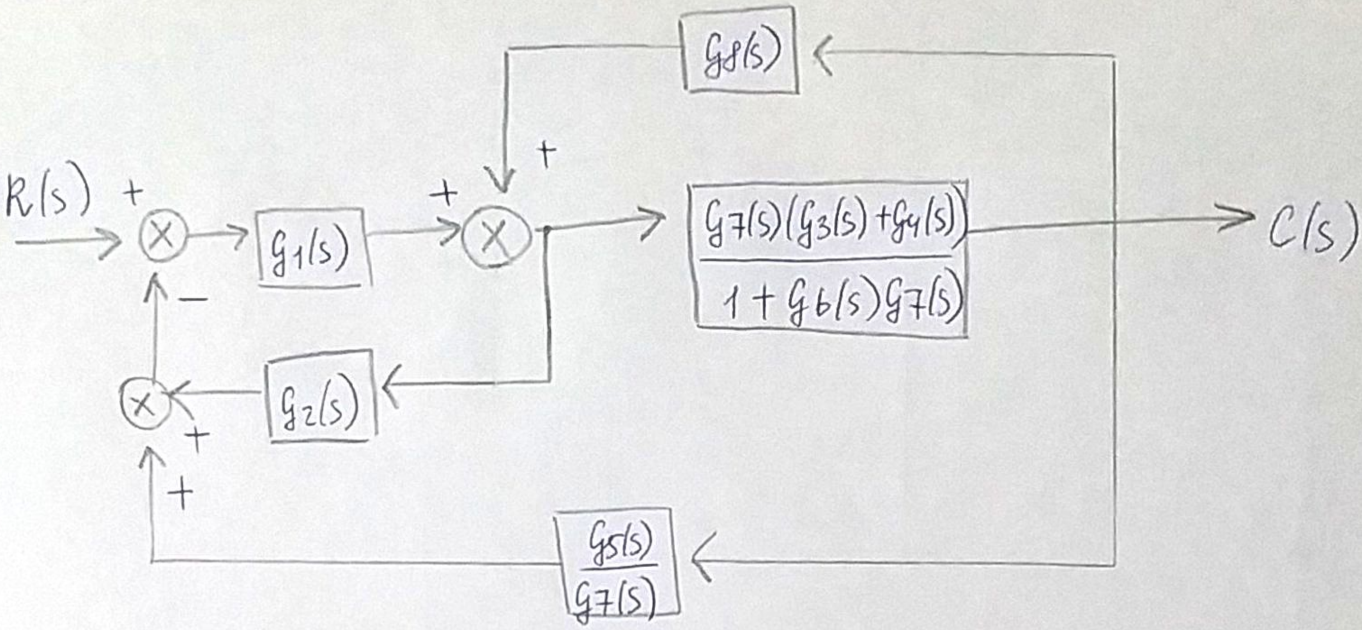
, where $G(s)$ is given above

B)

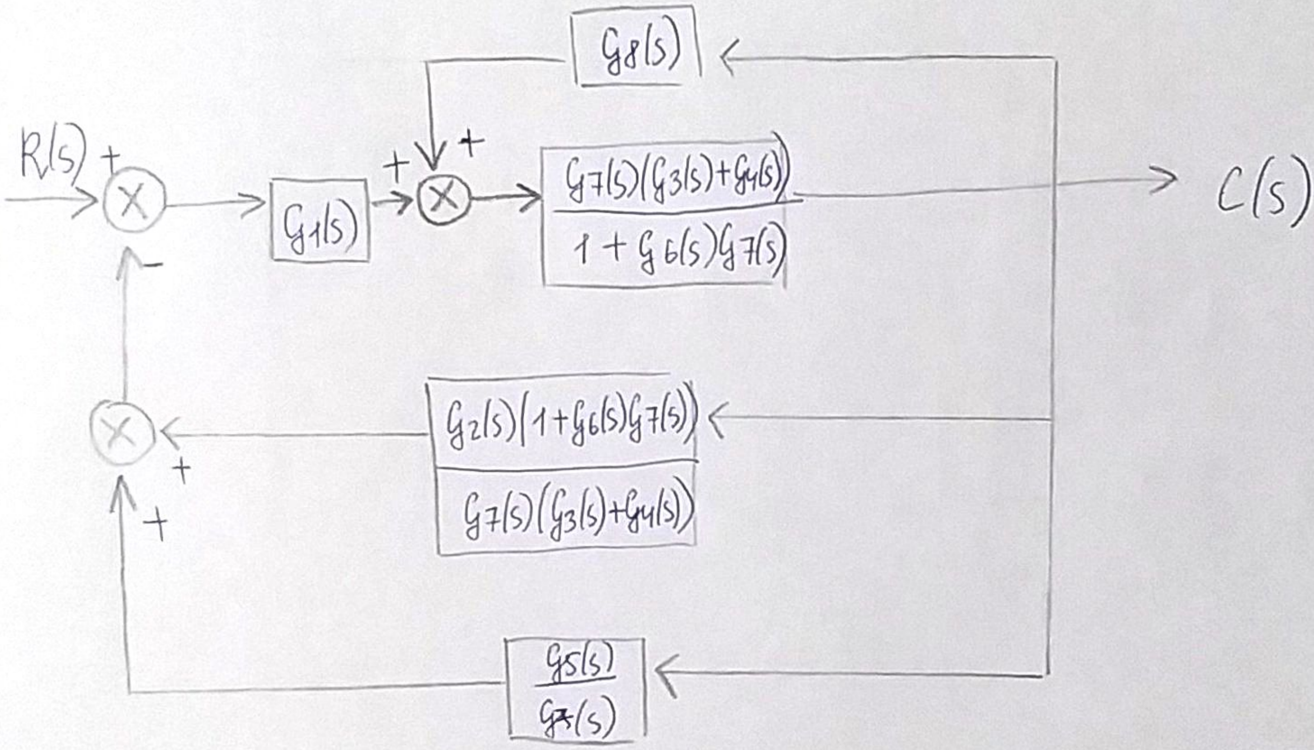

R(s)
G1(s)
G2(s)
G3(s)
G4(s)
G5(s)
G6(s)
G7(s)
G8(s)
C(s)


R(s)
G1(s)
G2(s)
G3(s)+G4(s)
G5(s)/G7(s)
G6(s)
G7(s)
G8(s)
C(s)

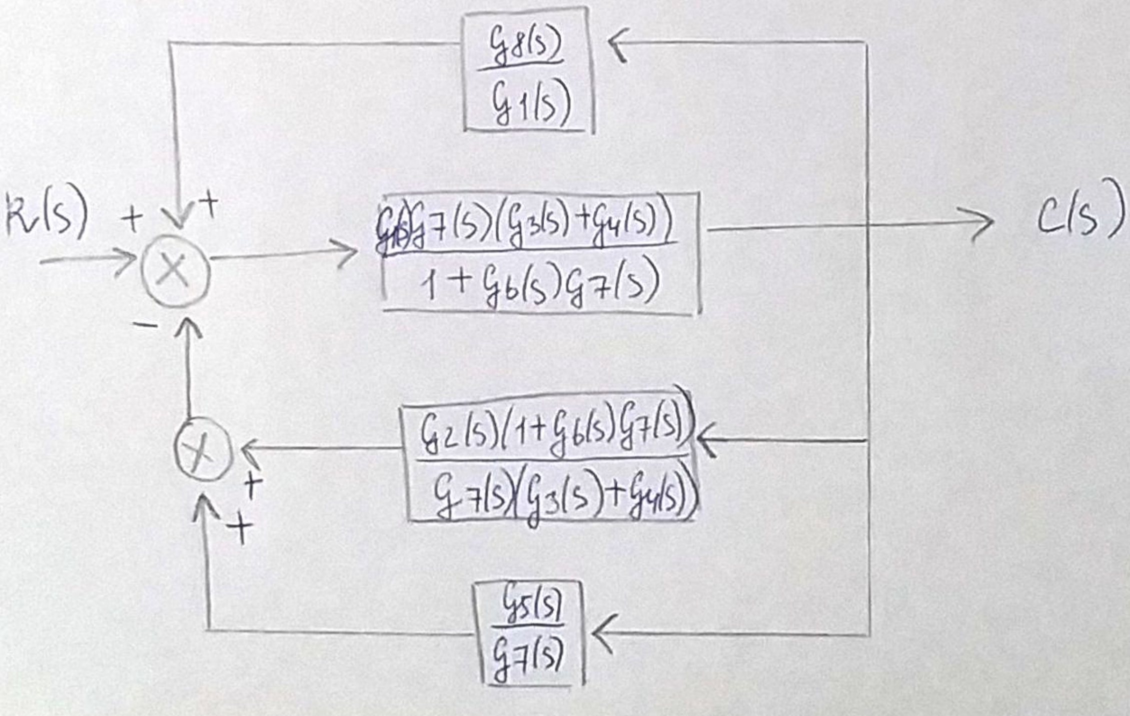

R(s)
G1(s)
G2(s)
G3(s)+G4(s)
G7(s)/(1+G6(s)G7(s))
G5(s)/G7(s)
G8(s)
C(s)



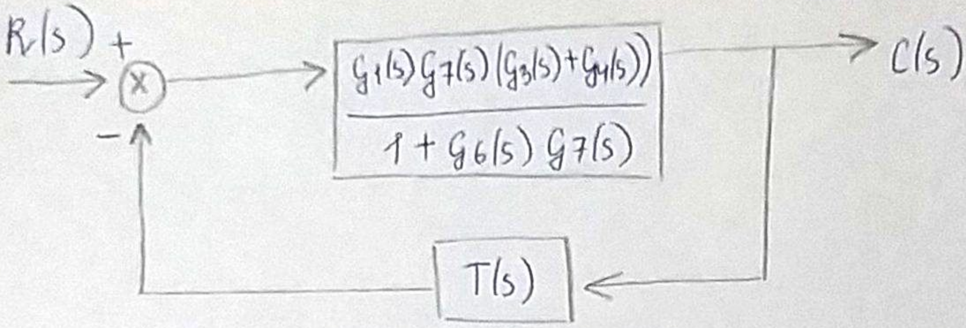
G8(s)
R(s)
G1(s)
G7(s)(G3(s)+G4(s))
1+G6(s)G7(s)
C(s)
G2(s)
G5(s)
G7(s)



G8(s)
R(s)
G1(s)
G7(s)(G3(s)+G4(s))
1+G6(s)G7(s)
C(s)
G2(s)(1+G6(s)G7(s))
G7(s)(G3(s)+G4(s))
G5(s)
G7(s)



G8(s)
G1(s)
R(s)
G7(s)(G3(s)+G4(s))
1+G6(s)G7(s)
C(s)
G2(s)(1+G6(s)G7(s))
G7(s)(G3(s)+G4(s))
G5(s)
G7(s)

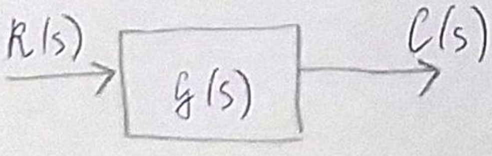


$$T(s) = \frac{G_5(s)}{G_7(s)} + \frac{G_2(s)\left(1+G_6(s)G_7(s)\right)}{G_7(s)\left(G_3(s)+G_4(s)\right)} - \frac{G_8(s)}{G_1(s)} =$$

$$\frac{G_1(s)G_5(s)\left(G_3(s)+G_4(s)\right) + G_1(s)G_2(s)\left(1+G_6(s)G_7(s)\right) - G_7(s)G_8(s)\left(G_3(s)+G_4(s)\right)}{G_1(s)G_7(s)\left(G_3(s)+G_4(s)\right)}$$

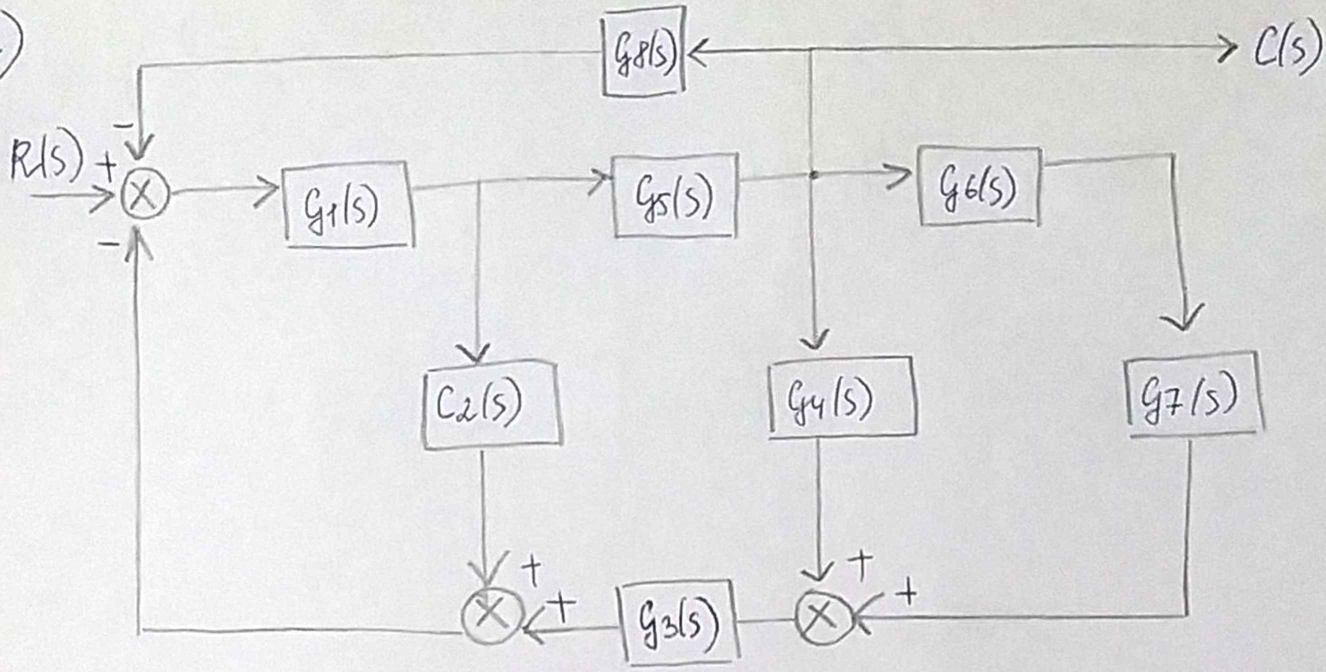
$$G(s) = \frac{C(s)}{R(s)} = \frac{\dfrac{G_1(s)G_7(s)\left(G_3(s)+G_4(s)\right)}{1+G_6(s)G_7(s)}}{1 + \dfrac{G_1(s)G_7(s)\left(G_3(s)+G_4(s)\right)}{1+G_6(s)G_7(s)} \cdot T(s)} =$$

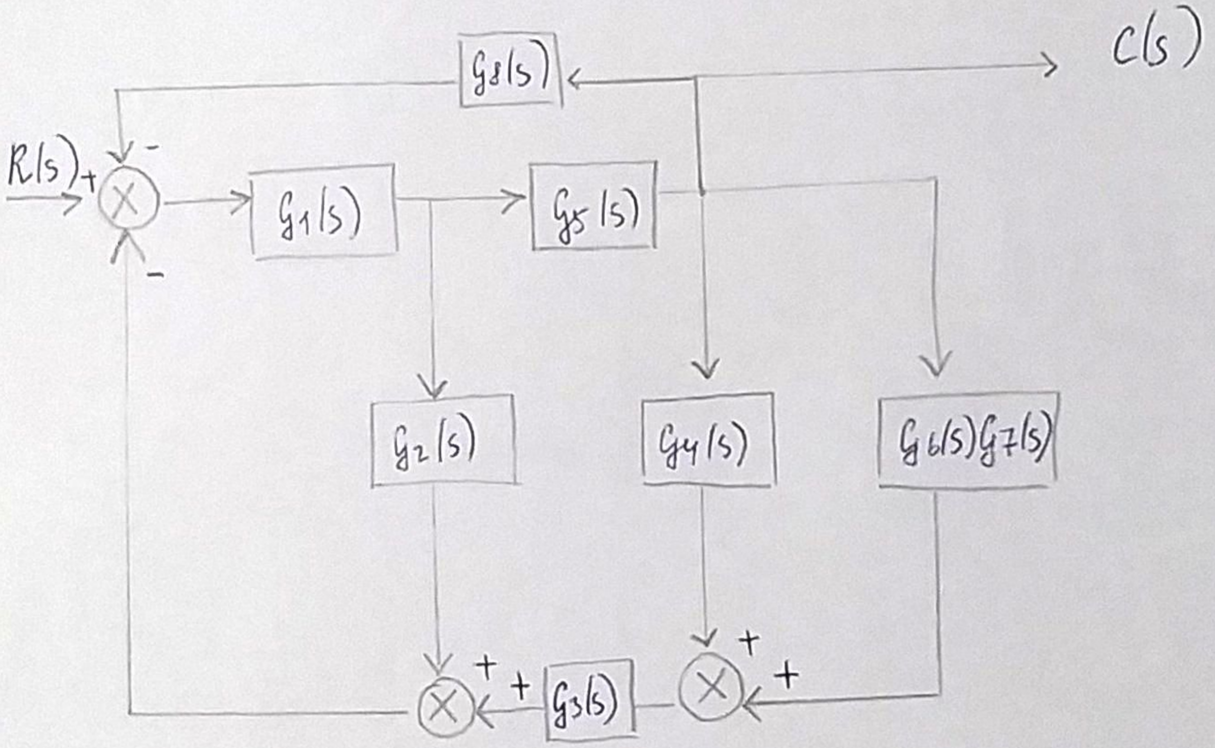
$$\frac{G_1(s)G_7(s)\left(G_3(s)+G_4(s)\right)}{1+G_6(s)G_7(s) + \left(G_3(s)+G_4(s)\right)\left(G_1(s)G_5(s) - G_7(s)G_8(s)\right) + G_1(s)G_2(s)\left(1+G_6(s)G_7(s)\right)}$$

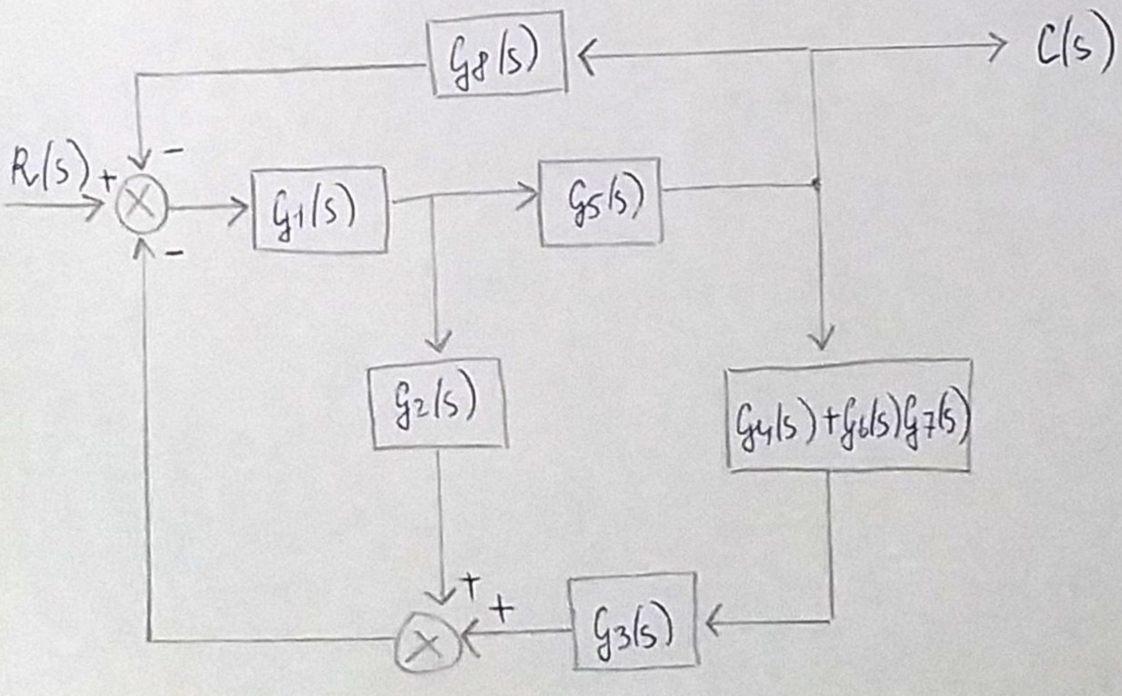


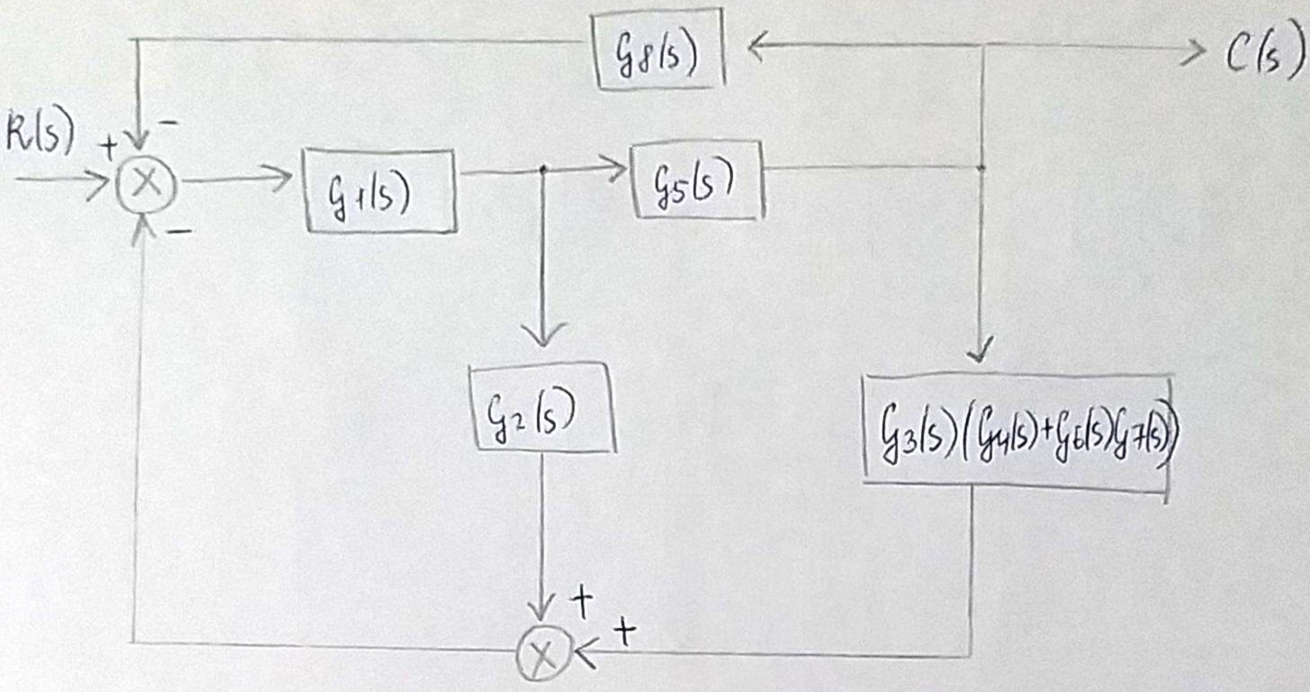
, where $G(s)$ is given above

c)

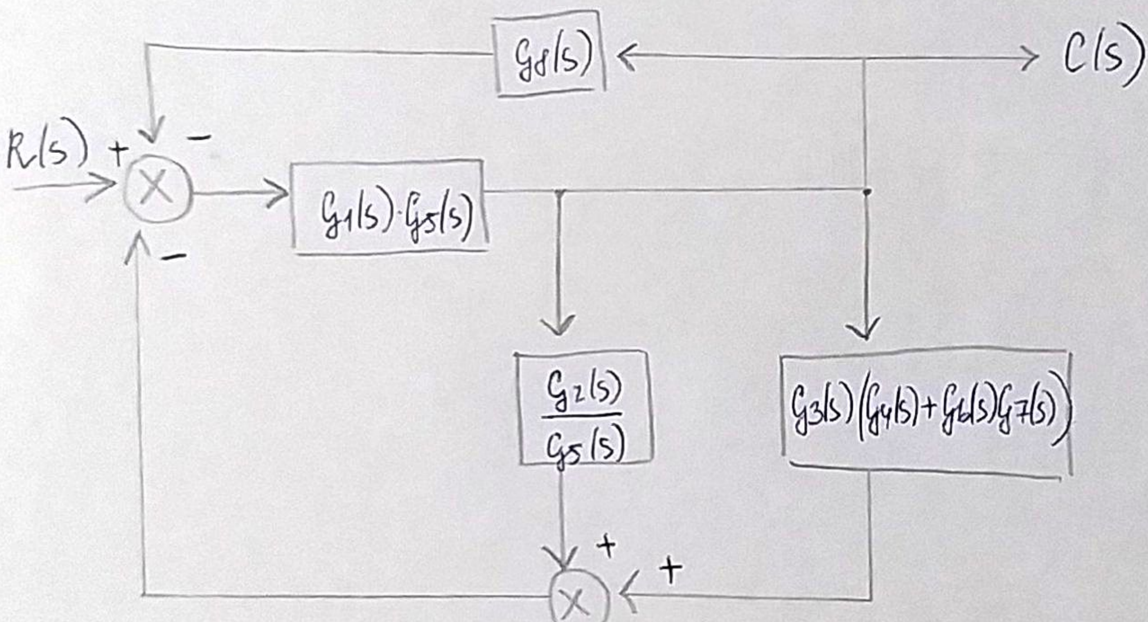

G8(s)
C(s)
R(s)
G1(s)
G5(s)
G6(s)
C2(s)
G4(s)
G7(s)
G3(s)


G8(s)
C(s)
R(s)
G1(s)
G5(s)
G2(s)
G4(s)
G6(s)G7(s)
G3(s)

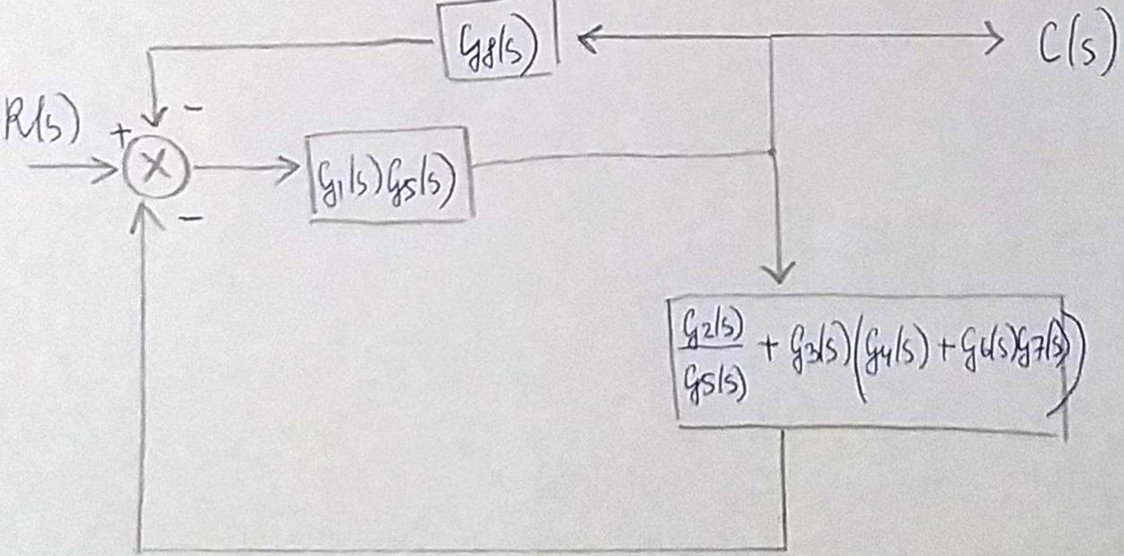

G8(s)
C(s)
R(s)
G1(s)
G5(s)
G2(s)
G4(s)+G6(s)G7(s)
G3(s)



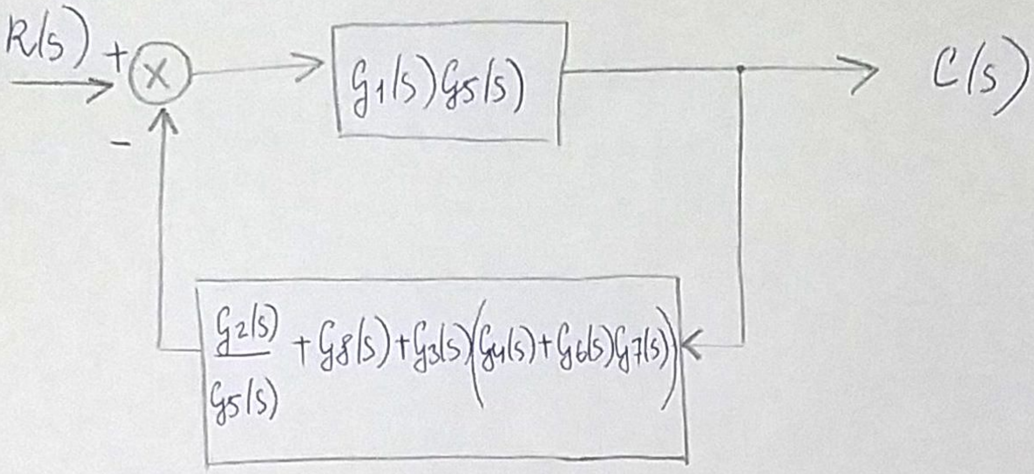
G8(s)
C(s)
R(s)
+
-
-
G1(s)
G5(s)
G2(s)
G3(s)(G4(s)+G6(s)G7(s))
+
+



G8(s)
C(s)
R(s)
+
-
-
G1(s)·G5(s)
G2(s)/G5(s)
G3(s)(G4(s)+G6(s)G7(s))
+
+

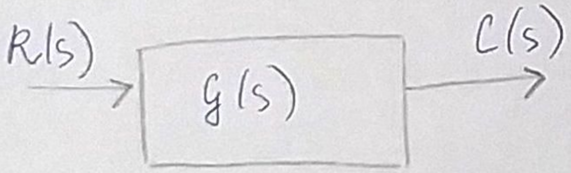


G8(s)
C(s)
R(s)
+
-
-
G1(s)G5(s)
G2(s)/G5(s) + G3(s)(G4(s)+G6(s)G7(s))



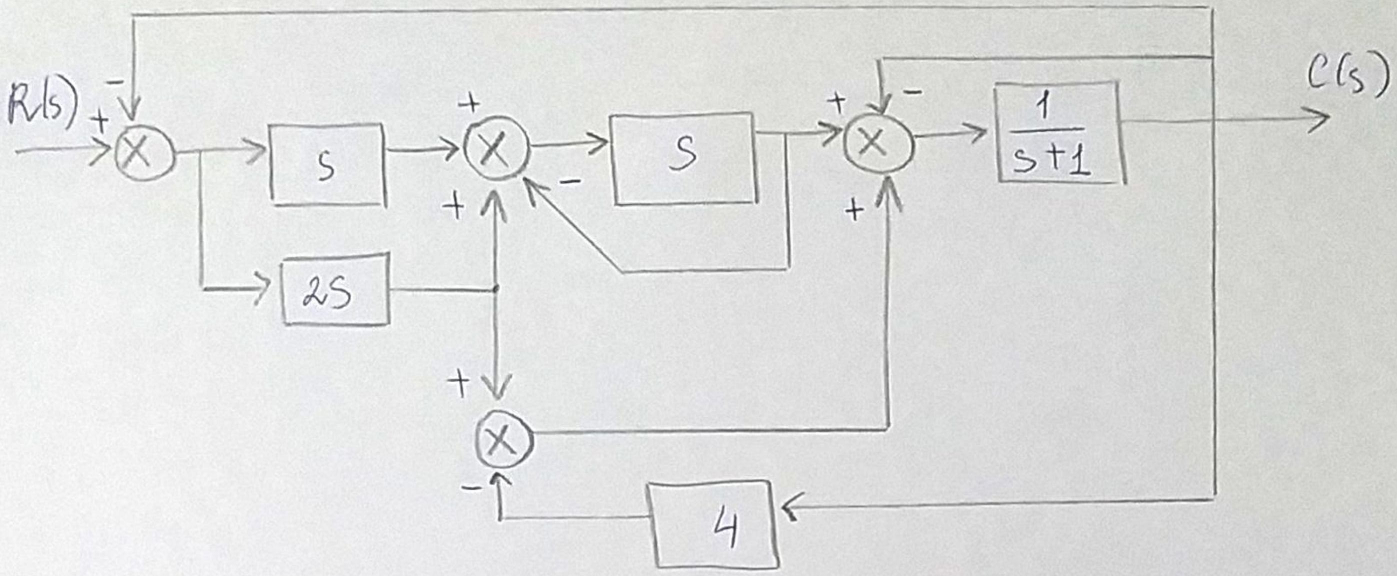
$$G(s) = \frac{C(s)}{R(s)} = \frac{G_1(s)G_5(s)}{1 + G_1(s)G_5(s)\left(\frac{G_2(s)}{G_5(s)} + G_8(s) + G_3(s)\left(G_4(s) + G_6(s)G_7(s)\right)\right)} =$$

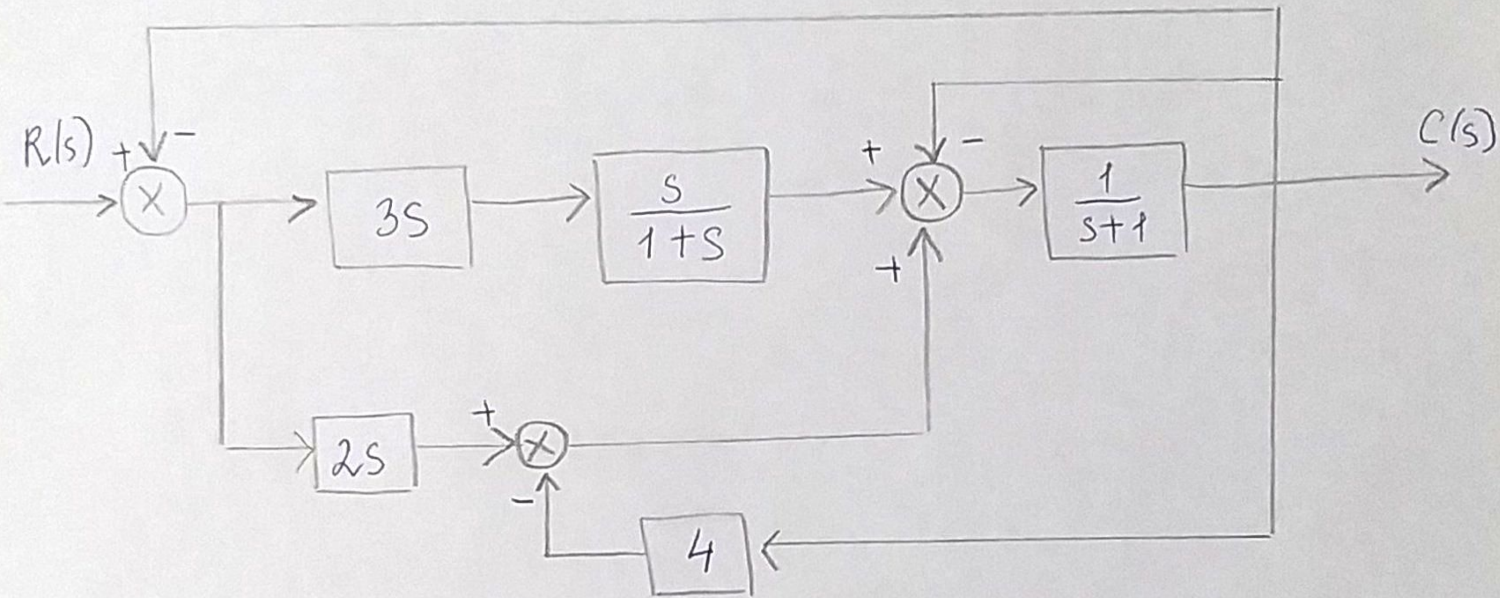
$$\frac{G_1(s)G_5(s)}{1 + G_1(s)\left[G_2(s) + G_5(s)G_8(s) + G_3(s)G_5(s)\left(G_4(s) + G_6(s)G_7(s)\right)\right]}$$

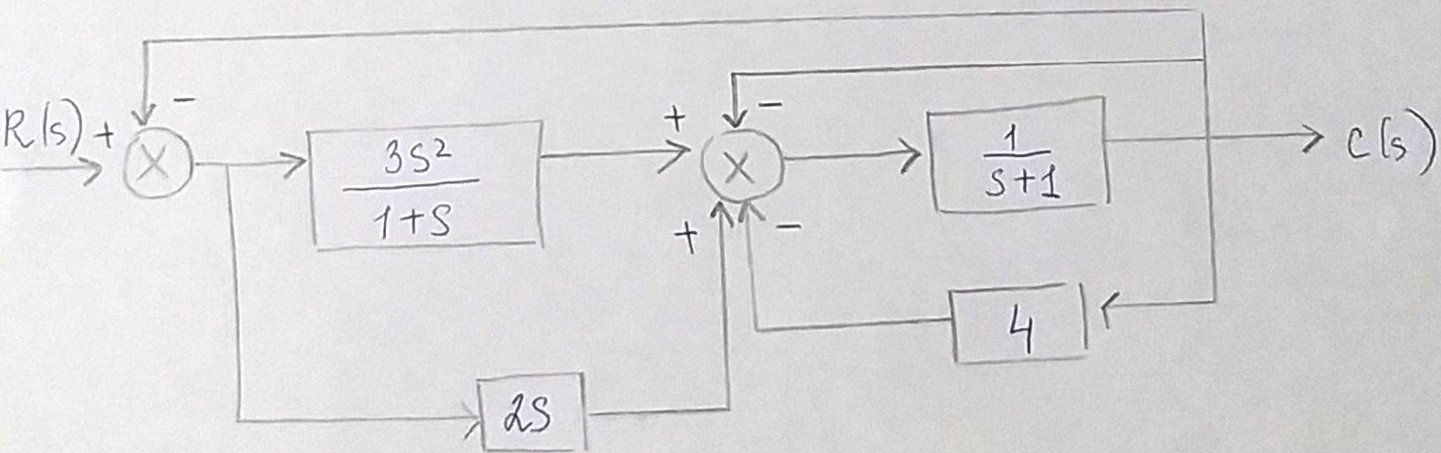


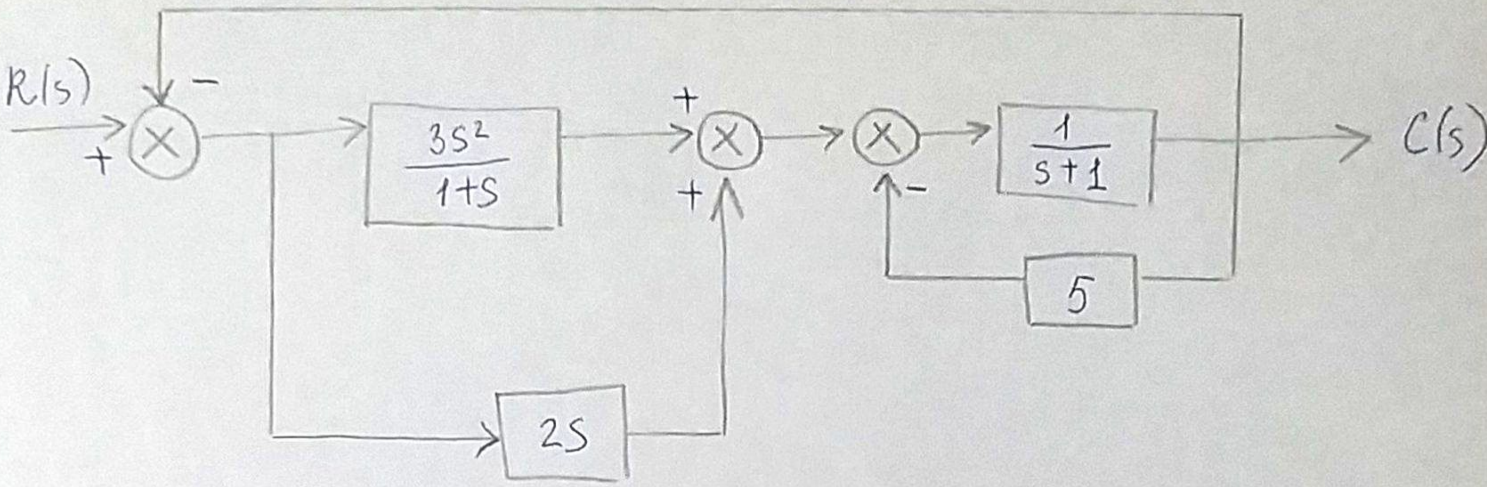
, where $G(s)$ is given above

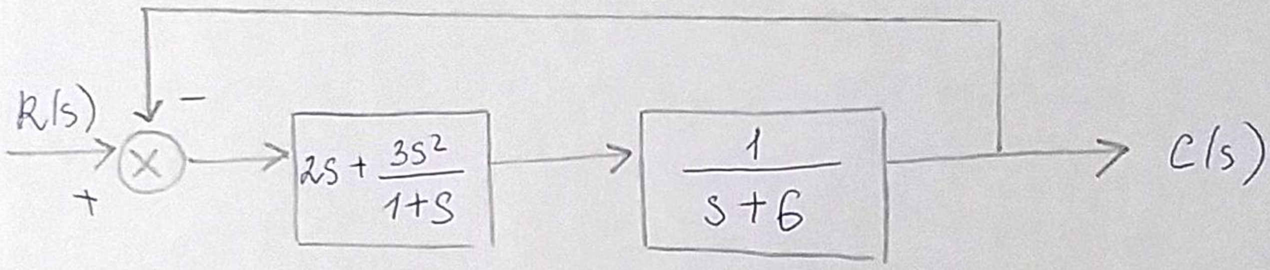
d)

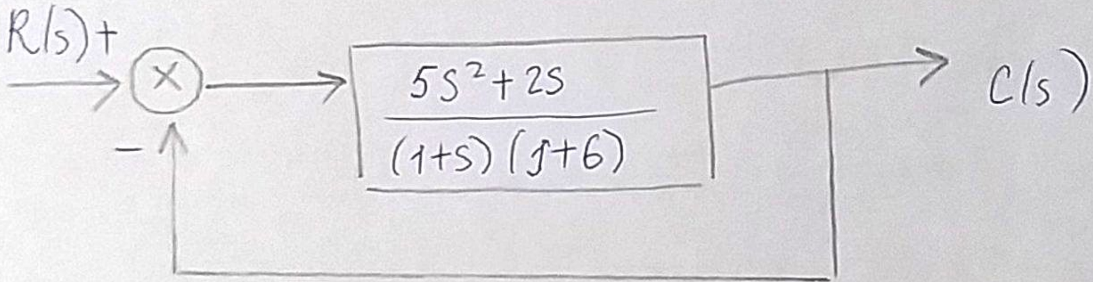


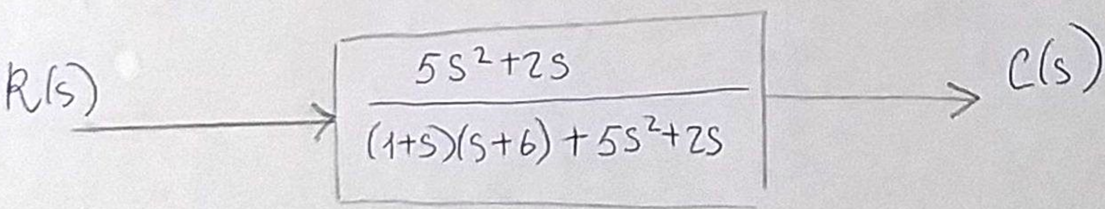


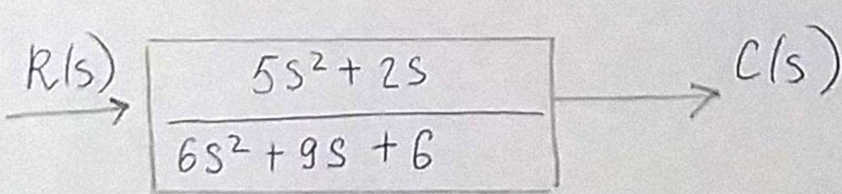






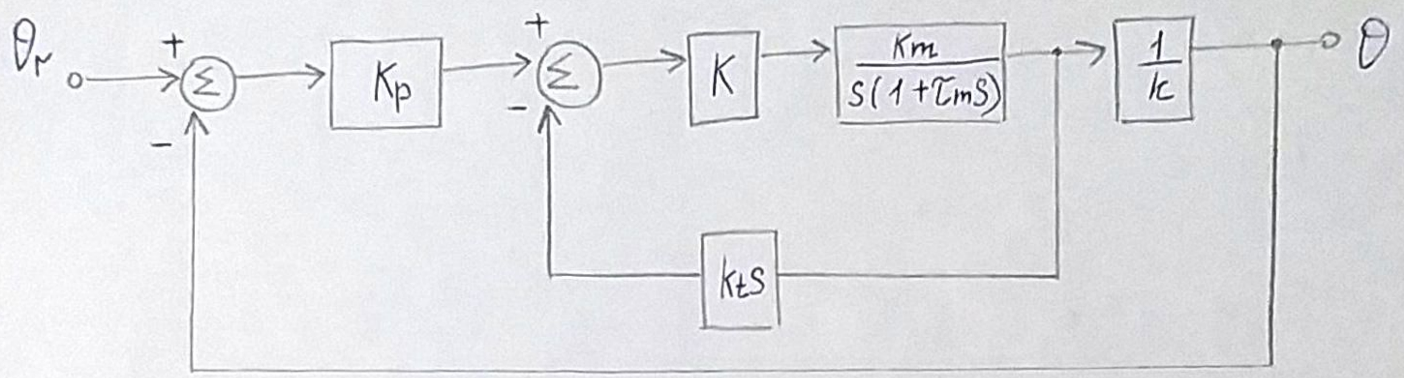




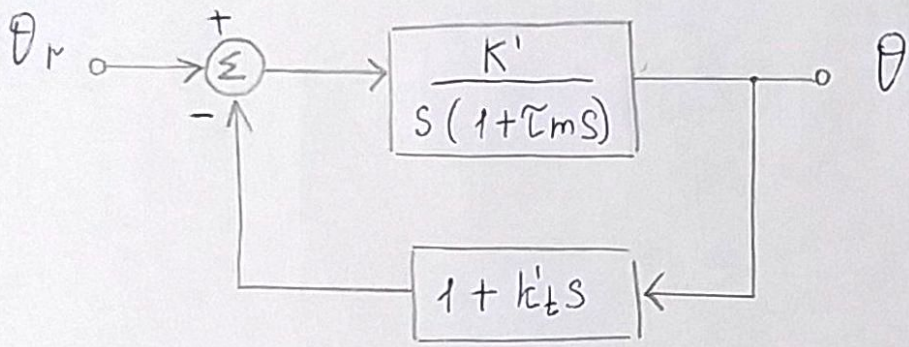


$$\Rightarrow G(s) = \frac{5s^2+2s}{6s^2+9s+6}$$

2. Problem 4.6



a)



b)

a) K', k_t' -?

b) system type, K_v -?

c) Does the addition of tachometer feedback with positive k_t increase or decrease K_v -?

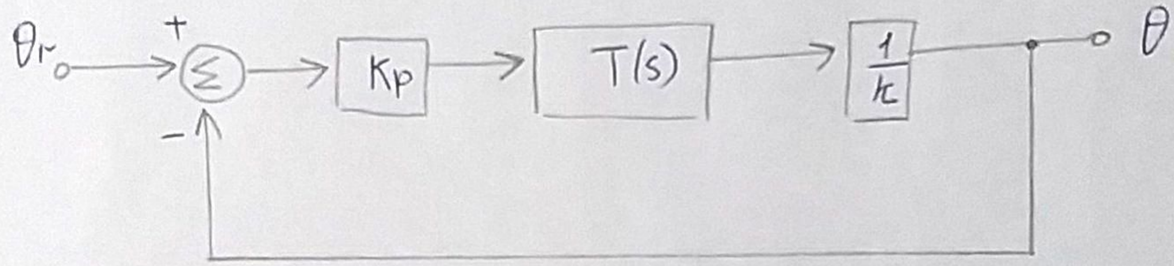
a) From Fig b),

$$\frac{\theta(s)}{\theta_r(s)} = \frac{\dfrac{K'}{s(1+\tau_m s)}}{1+\dfrac{K'(1+k_t' s)}{s(1+\tau_m s)}} = \frac{K'}{s(1+\tau_m s)+K'(1+k_t' s)}$$

$$= \frac{K'}{s + \tau_m s^2 + K' + K' k_t' s} \qquad [1]$$

From Fig a),

$$T(s) = \frac{\dfrac{KK_m}{s(1+\tau_m s)}}{1 + \dfrac{KK_m k_t s}{s(1+\tau_m s)}} = \frac{KK_m}{s(1+\tau_m s) + KK_m k_t s}$$



$$\frac{\theta(s)}{\theta_r(s)} = \frac{\dfrac{K_p KK_m}{k(s(1+\tau_m s) + KK_m k_t s)}}{1 + \dfrac{K_p KK_m}{k(s(1+\tau_m s) + KK_m k_t s)}} =$$

$$\frac{K_p KK_m}{k(s(1+\tau_m s) + KK_m k_t s) + K_p KK_m} = \frac{K_p KK_m}{ks + k\tau_m s^2 + KK_m k_t k s + K_p KK_m}$$

$$= \frac{\dfrac{K_p KK_m}{k}}{s + \tau_m s^2 + \dfrac{K_p KK_m}{k} + KK_m k_t s} \qquad [2]$$

Comparing [1] and [2],

$$K' = \frac{K_p K K_m}{k} \qquad K' k_t' = K K_m k_t$$

$$\frac{K_p \cancel{K K_m}}{k} k_t' = \cancel{K K_m} k_t$$

$$k_t' = \frac{k k_t}{K_p}$$

$$\boxed{K' = \frac{K_p K K_m}{k}, \quad k_t' = \frac{k k_t}{K_p}}$$

b) Let $L(s)$ be an open-loop transfer function

$$L(s) = \frac{K_p}{k} T(s) = \frac{K_p K K_m}{k\left(s(1+\tau_m s) + K K_m k_t s\right)} = \frac{K_p K K_m}{ks + k\tau_m s^2 + K K_m k_t k s} =$$

$$\frac{K_p K K_m}{s\left(k\tau_m s + K K_m k_t k + k\right)}$$

As $L(s)$ has one integrator, $\boxed{\text{the system type is Type-1}}$

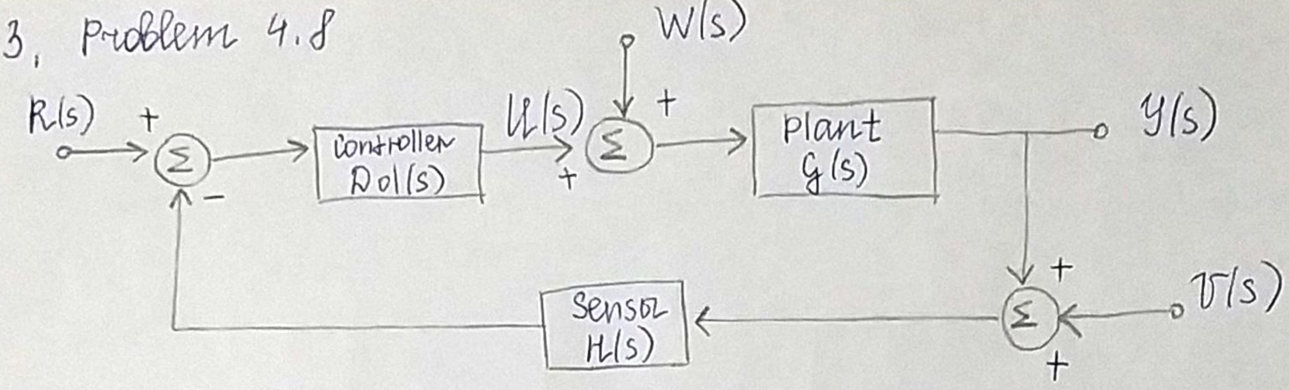
$$K_v = \lim_{s \to 0} s L(s) = \lim_{s \to 0} s \cdot \frac{K_p K K_m}{s(k\tau_m s + K K_m k_t k + k)} = \frac{K_p K K_m}{K K_m k_t k + k} =$$

$$\frac{\frac{K_p K K_m}{k}}{K K_m k_t + 1} = \frac{K'}{K' k_t' + 1}$$

$$\boxed{K_v = \frac{K'}{K' k_t' + 1}}$$

c) As $K_v = \dfrac{K_p K K_m}{K K_m k_t k + k}$, the addition of tachometer feedback with positive k_t <u>decreases</u> K_v.

3. Problem 4.8



$$G(s) = \frac{1}{s} \qquad D_c(s) = \frac{2(s+1)}{s} \qquad H(s) = \frac{100}{s+100}$$

a) $W=0$ $\quad \dfrac{Y(s)}{R(s)}$ - ?

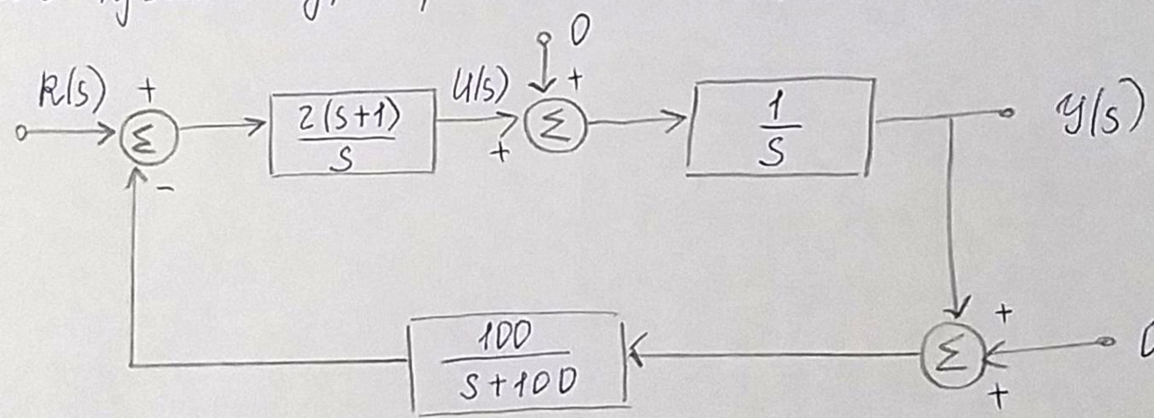
b) $R=0$ $\quad \dfrac{Y(s)}{W(s)}$ - ?

c) R is a unit-step input, $W=0$ the tracking error - ?

d) R is a unit-ramp input, $W=0$ the tracking error - ?

e) the system type, the error coefficient - ?

a)

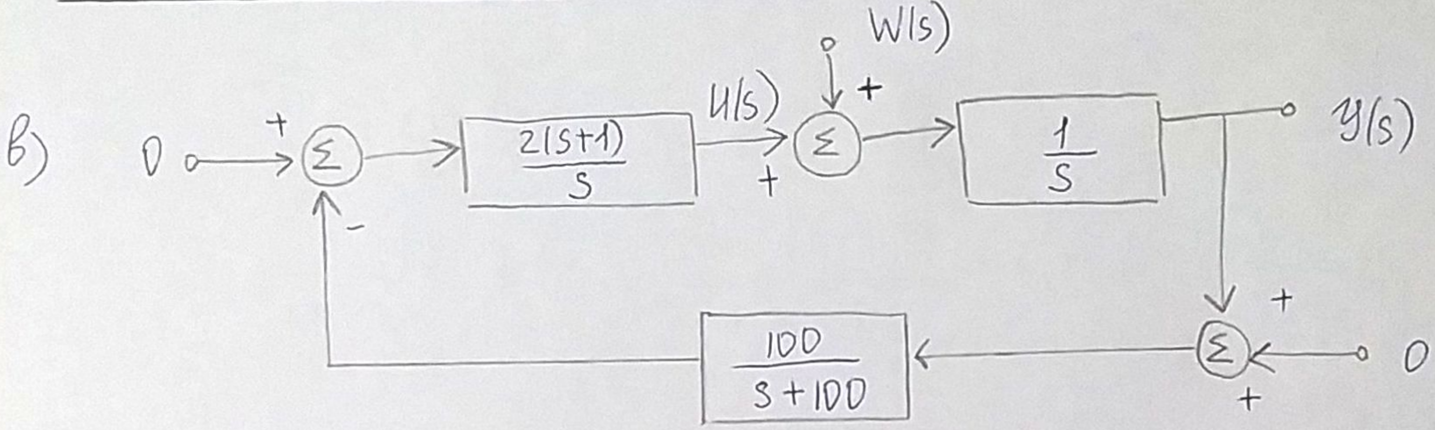


$$\frac{Y(s)}{R(s)} = \frac{\frac{2(s+1)}{s}\cdot\frac{1}{s}}{1+\frac{2(s+1)}{s}\cdot\frac{1}{s}\cdot\frac{100}{s+100}} = \frac{\frac{2(s+1)}{s^2}}{\frac{s^2(s+100)+200(s+1)}{s^2(s+100)}} =$$

$$\frac{2(s+1)\cdot s^2(s+100)}{s^2(s^3+100s^2+200s+200)} = \frac{2(s+1)(s+100)}{s^3+100s^2+200s+200}$$

$$\boxed{\frac{Y(s)}{R(s)} = \frac{2(s+1)(s+100)}{s^3+100s^2+200s+200}}$$

b)



$$\frac{Y(s)}{W(s)} = \frac{\frac{1}{s}}{1-\left(-\frac{1}{s}\cdot\frac{100}{s+100}\cdot\frac{2(s+1)}{s}\right)} = \frac{\frac{1}{s}}{\frac{s^2(s+100)+200(s+1)}{s^2(s+100)}} =$$

$$\frac{1\cdot s^2(s+100)}{s\cdot(s^3+100s^2+200s+200)} = \frac{s(s+100)}{s^3+100s^2+200s+200}$$

$$\boxed{\frac{Y(s)}{W(s)} = \frac{s(s+100)}{s^3+100s^2+200s+200}}$$

c) $E(s) = R(s) - Y(s) = R(s) - \frac{2(s+1)(s+100)}{s^3+100s^2+200s+200}R(s) =$

$$\left(1-\frac{2(s+1)(s+100)}{s^3+100s^2+200s+200}\right)R(s) = \left(\frac{s^3+98s^2-2s}{s^3+100s^2+200s+200}\right)R(s)$$

As $R(s)=\frac{1}{s}$, $E(s) = \frac{s(s^2+98s-2)}{s^3+100s^2+200s+200}\cdot\frac{1}{s} =$

$$\frac{s^2+98s-2}{s^3+100s^2+200s+200}$$

$$\lim_{t\to\infty} e(t) = \lim_{s\to 0} sE(s) = \lim_{s\to 0} s\left(\frac{s^2+98s-2}{s^3+100s^2+200s+200}\right) = 0$$

$$\Rightarrow \boxed{e_{ss} = 0}$$

d) $$E(s) = \left(\frac{s^3+98s^2-2s}{s^3+100s^2+200s+200}\right) \cdot R(s)$$

as $R(s) = \frac{1}{s^2}$, $E(s) = \dfrac{s(s^2+98s-2)}{s^3+100s^2+200s+200}\left(\dfrac{1}{s^2}\right) =$

$$\frac{s^2+98s-2}{s(s^3+100s^2+200s+200)}$$

$$\lim_{t\to\infty} e(t) = \lim_{s\to 0} sE(s) = \lim_{s\to 0} \cancel{s}\,\frac{s^2+98s-2}{\cancel{s}(s^3+100s^2+200s+200)} =$$

$$-\frac{2}{200} = -0.01$$

$$\Rightarrow \boxed{e_{ss} = -0.01}$$

e) as e_{ss} is a nonzero constant if R is a unit-ramp input, $\boxed{\text{the system type is Type-1}}$

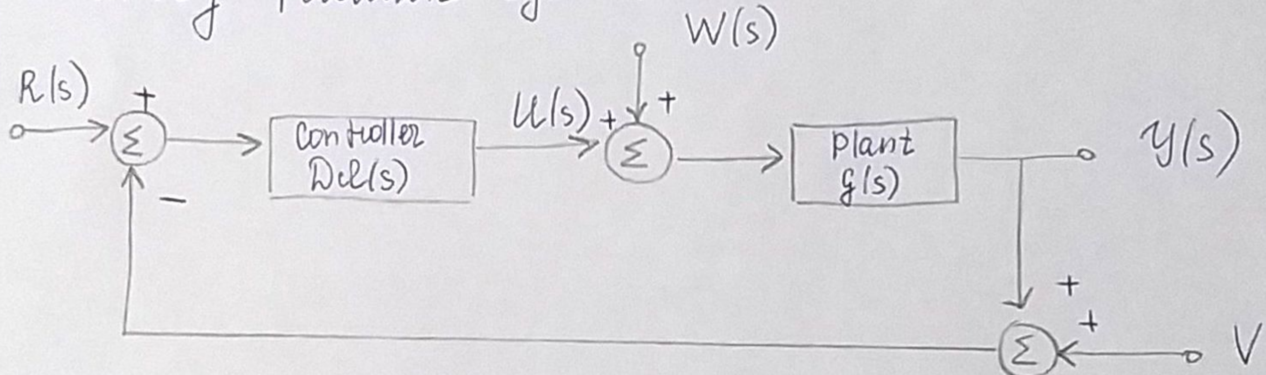
For a type-1 system, the error coefficient is the velocity error constant

$$e_{ss} = \frac{1}{K_v} \Rightarrow K_v = \frac{1}{e_{ss}} = \frac{1}{-0.01} = -100$$

$$\boxed{K_v = -100}$$

4. Problem 4.12

a unity feedback system



$$\frac{Y(s)}{R(s)} = T(s) = \frac{\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

system type, error constant - ?

$$\frac{Y(s)}{R(s)} = \frac{G(s)D_{cl}(s)}{1 + G(s)D_{cl}(s)}$$

$$\frac{G(s)D_{cl}(s)}{1 + G(s)D_{cl}(s)} = \frac{\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

$$\frac{1 + G(s)D_{cl}(s)}{G(s)D_{cl}(s)} = \frac{s^2 + 2\zeta\omega_n s + \omega_n^2}{\omega_n^2}$$

$$1+\frac{1}{G(s)D_{cl}(s)} = \frac{s^2+2\zeta\omega_n s+\omega_n^2}{\omega_n^2}$$

$$\frac{1}{G(s)D_{cl}(s)} = \frac{s^2+2\zeta\omega_n s+\omega_n^2}{\omega_n^2} - 1$$

$$\frac{1}{G(s)D_{cl}(s)} = \frac{s(s+2\zeta\omega_n)}{\omega_n^2}$$

$$G(s)D_{cl}(s) = \frac{\omega_n^2}{s(s+2\zeta\omega_n)}$$

$$L(s) = \frac{\omega_n^2}{s(s+2\zeta\omega_n)}$$

$L(s)$ has one integrator, $\Rightarrow$ $\boxed{\text{the system type is Type-1}}$

For Type-1, corresponding error constant is velocity error constant

$$K_v = \lim_{s\to 0} sL(s) = \lim_{s\to 0} \frac{\cancel{s}\,\omega_n^2}{\cancel{s}(s+2\zeta\omega_n)} = \frac{\omega_n}{2\zeta}$$

$$\boxed{K_v = \frac{\omega_n}{2\zeta}}$$

5. Problem 4.13

$$G(s) = \frac{1}{s^2 + 2\zeta s + 1} \qquad D_c(s) = \frac{K(s+a)}{(s+b)}$$

- a unity feedback structure

a) Ignoring stability, what are the constraints on K, a, b so that the system is Type 1?

b) What are the constraints placed on K, a, b so that the system is both stable and Type 1?

c) What are the constraints on a, b so that the system is both Type 1 and remains stable for every positive value for K?

a) $$L(s) = G(s)D_c(s) = \frac{K(s+a)}{(s+b)(s^2+2\zeta s+1)}$$

Type - 1 systems : $L(s)$ has one integrator

$\Rightarrow b = 0$

$a \neq 0$ - not to cancel pole at origin

$K \neq 0$ - so that $L(s) \neq 0$

The constraints are
$b = 0,\ a \neq 0,\ K \neq 0$

b) For Type-1, $L(s) = \dfrac{K(s+a)}{s(s^2+2\zeta s+1)}$ $(b=0, a \neq 0, K \neq 0)$

For stability, $K(s+a) + s(s^2+2\zeta s+1) = 0$

must have roots with strictly negative real part

$$s^3 + 2\zeta s^2 + s + Ks + Ka = 0$$

$$s^3 + 2\zeta s^2 + (K+1)s + Ka = 0$$

Using Routh stability criterion,

$$\begin{array}{c|cc} s^3 & 1 & K+1 \\ s^2 & 2\zeta & Ka \\ s^1 & \dfrac{2\zeta(K+1) - Ka}{2\zeta} & \\ s^0 & Ka & \end{array}$$

$\Rightarrow$ $2\zeta > 0$, $\dfrac{2\zeta(K+1) - Ka}{2\zeta} > 0$, $Ka > 0$ must be satisfied

The constraints are :

$$\boxed{b = 0, \quad 2\zeta(K+1) - Ka > 0, \quad Ka > 0}$$

c) If $K > 0$, $Ka > 0$ becomes $a > 0$

$$2\zeta(K+1) - Ka > 0$$

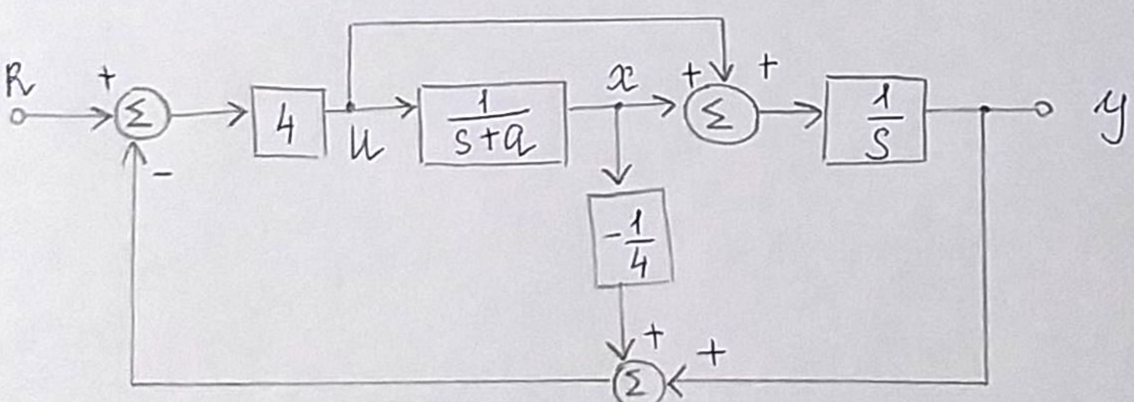
$$2\zeta K + 2\zeta - Ka > 0$$

$$2\zeta + K(2\zeta - a) > 0 \qquad (2\zeta > 0,\ K > 0,\ a > 0)$$

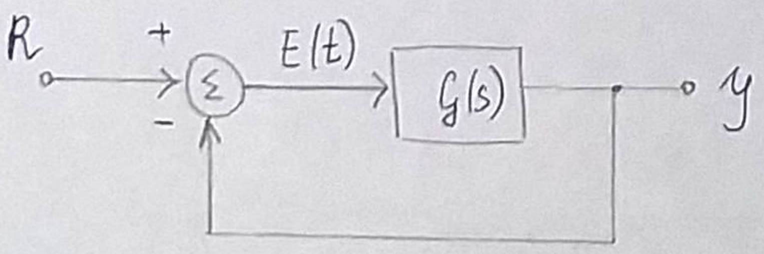
$\Rightarrow$ $a < 2\zeta$ so that the system remains stable for every positive value for K

$$\boxed{\text{The constraints are: } \beta = 0, \quad 0 < a < 2\zeta}$$

6. Problem 4.20



a)



b)

a) $G(s)$ - ?

b) $a = 1$, system type, error constant - ?

c) $a = 1 + \delta a$, system type, error constant - ?

a) From Fig a), $Y(s) = \frac{1}{s}\left(1 + \frac{1}{s+a}\right) U(s)$

$$U(s) = 4 \left[R(s) - \left(Y(s) - \frac{1}{4} X(s)\right)\right]$$

$$X(s) = \frac{1}{s+a} U(s)$$

$$\Rightarrow U(s) = 4R(s) - 4Y(s) + \frac{1}{s+a} U(s)$$

$$\left(1 - \frac{1}{s+a}\right) U(s) = 4 \left[R(s) - Y(s)\right]$$

$$\frac{s+a-1}{s+a} U(s) = 4\left[R(s) - Y(s)\right]$$

$$U(s) = \frac{4(s+a)}{s+a-1} \left[R(s) - Y(s)\right]$$

$$\Rightarrow Y(s) = \frac{1}{s} \cdot \frac{s+a+1}{\cancel{s+a}} \cdot \left(\frac{4\cancel{(s+a)}}{s+a-1} \left[R(s) - Y(s)\right]\right) =$$

$$\frac{4(s+a+1)}{s(s+a-1)} \left[R(s) - Y(s)\right]$$

From Fig b), $y(s) = G(s) \cdot [R(s) - y(s)]$

$$\Rightarrow \boxed{G(s) = \frac{4(s+a+1)}{s(s+a-1)}}$$

b) If $a = 1$, $G(s) = \frac{4(s+2)}{s \cdot s} = \frac{4(s+2)}{s^2}$

As open-loop transfer function has two integrators,

$\boxed{\text{the system type is Type-2}}$

Corresponding error constant for Type-2 is acceleration error constant : $K_a = \lim_{s\to 0} s^2 G(s) = \lim_{s \to 0} s^2 \cdot \frac{4(s+2)}{s^2} = 8$

$$\boxed{K_a = 8}$$

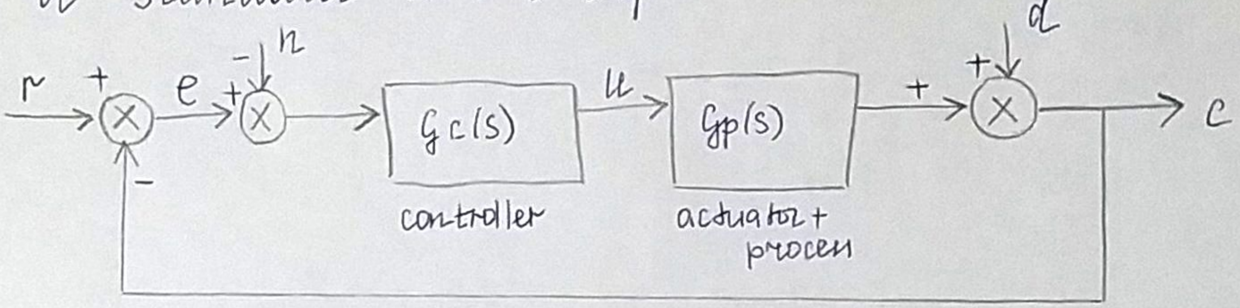
c) If $a = 1 + \delta a$, $G(s) = \frac{4(s+2+\delta a)}{s(s+\delta a)}$

As $G(s)$ has one integrator, $\boxed{\text{the system type is Type-1}}$

Corresponding error constant for Type-1 is velocity error constant : $K_v = \lim_{s \to 0} s\,G(s) = \lim_{s\to 0} \frac{\cancel{s} \cdot 4(s+2+\delta a)}{\cancel{s}(s+\delta a)} = \frac{4(2+\delta a)}{\delta a}$

$$\boxed{K_v = \frac{4(2+\delta a)}{\delta a}}$$

7. a standard control loop



$$G_c(s) = \frac{s+4}{s} \qquad G_p(s) = \frac{250(s+6)(s+7)}{(s+3)(s^2+2s+12)} \qquad (L(s) = G_c(s)G_p(s))$$

the steady-state errors for inputs $2u(t)$, $2tu(t)$, $3t^2u(t)$ -?

a) $r(t) = 2u(t)$ $\qquad R(s) = \frac{2}{s}$

$$\lim_{t\to\infty} e(t) = \lim_{s\to 0} sE(s) = \lim_{s\to 0} sS(s)R(s) = \lim_{s\to 0} s\frac{1}{1+L(s)}\frac{2}{s} =$$

$$\lim_{s\to 0} \frac{2}{1+\frac{250(s+4)(s+6)(s+7)}{s(s+3)(s^2+2s+12)}} = \lim_{s\to 0} \frac{2s(s+3)(s^2+2s+12)}{s(s+3)(s^2+2s+12)+250(s+4)(s+6)(s+7)} =$$

0

$$\Rightarrow \boxed{e_{ss} = 0 \quad \text{for } r(t) = 2u(t)}$$

b) $r(t) = 2tu(t)$ $\qquad R(s) = \frac{2}{s^2}$

$$\lim_{t\to\infty} e(t) = \lim_{s\to 0} s\frac{1}{1+L(s)}\frac{2}{s^2} = \lim_{s\to 0}\frac{2}{s+sL(s)} =$$

$$\lim_{s\to 0} \frac{2}{s+\frac{250(s+4)(s+6)(s+7)}{(s+3)(s^2+2s+12)}} = \lim_{s\to 0} \frac{2(s+3)(s^2+2s+12)}{s(s+3)(s^2+2s+12)+250(s+4)(s+6)(s+7)} =$$

$$\frac{2\cdot 3\ 12}{250\ 4\ 6\ 7} = \frac{3}{1750}$$

$$\Rightarrow \boxed{e_{ss} = \frac{3}{1750} \quad \text{for } r(t) = 2t\,u(t)}$$

c) $r(t) = 3t^2 u(t)$ $\qquad R(s) = \frac{6}{s^3}$

$$\lim_{t\to\infty} e(t) = \lim_{s\to 0} s \frac{1}{1+L(s)} \frac{6}{s^3} = \lim_{s\to 0} \frac{6}{s^2 + L(s)s^2} =$$

$$\lim_{s\to 0} \frac{6}{s^2 + \frac{250s(s+4)(s+6)(s+7)}{(s+3)(s^2+2s+12)}} = \lim_{s\to 0} \frac{6(s+3)(s^2+2s+12)}{s^2(s+3)(s^2+2s+12) + 250s(s+4)(s+6)(s+7)}$$

$$= \infty$$

$$\Rightarrow \boxed{e_{ss} = \infty \quad \text{for } r(t) = 3t^2 u(t)}$$

8. A standard control loop

$$G_c(s) = \frac{3}{s+7} \qquad G_p(s) = \frac{10}{s^2+4s+7} \qquad (L(s) = G_c(s)\cdot G_p(s))$$

the static error constants K_p, K_v, K_a -?

the steady-state errors for inputs $5u(t)$, $10t u(t)$, $36t^2u(t)$)

$$K_p = \lim_{s\to 0} L(s) = \lim_{s\to 0} \frac{30}{(s+7)(s^2+4s+7)} = \frac{30}{7\cdot 7} = \frac{30}{49}$$

$$K_v = \lim_{s\to 0} sL(s) = \lim_{s\to 0} \frac{30s}{(s+7)(s^2+4s+7)} = 0$$

$$K_a = \lim_{s\to 0} s^2L(s) = \lim_{s\to 0} \frac{30s^2}{(s+7)(s^2+4s+7)} = 0$$

$$\Rightarrow \boxed{K_p = \frac{30}{49}, \quad K_v = 0, \quad K_a = 0}$$

As the system is a type-0 system,

for $r(t) = 5u(t)$ $\quad e_{ss} = 5 \cdot \frac{1}{1+K_p} = 5 \cdot \frac{1}{1+\frac{30}{49}} = \frac{245}{79}$

for $r(t) = 10tu(t)$ $\quad e_{ss} = \infty$

for $r(t) = 36t^2u(t)$ $\quad e_{ss} = \infty$

$$\Rightarrow \boxed{\begin{array}{ll} e_{ss} = \frac{245}{79} & \text{for } r(t) = 5u(t) \\ e_{ss} = \infty & \text{for } r(t) = 10tu(t) \\ e_{ss} = \infty & \text{for } r(t) = 36t^2u(t) \end{array}}$$