

IT@CookBook

핵심이 보이는 제어공학(3판)

연습문제 정답

Chapter 01

- 1.1 ② 1.2 ③ 1.3 ③ 1.4 ① 1.5 ①
- 1.6 ④ 1.7 ① 1.8 ② 1.9 ③ 1.10 ④
- 1.11 ① 1.12 ④ 1.13 ③ 1.14 ④ 1.15 ②
- 1.16 ④ 1.17 ④ 1.18 ① 1.19 ② 1.20 ②
- 1.21 ③ 1.22 ③ 1.23 ① 1.24 ③ 1.25 ④
- 1.26 ③ 1.27 ④

1.28 ~ 1.32 생략

1.33



Chapter 02

2.1 ② 2.2 ③ 2.3 ④ 2.4 ① 2.5 ②

2.6 ④ 2.7 ① 2.8 ② 2.9 ④ 2.10 ③

2.11 ② 2.12 ① 2.13 ④ 2.14 ④ 2.15 ④

2.16 ① 2.17 ② 2.18 ② 2.19 ① 2.20 ③

2.21 ① 2.22 ④ 2.23 ② 2.24 ① 2.25 ①

$$2.26 \quad I(s) = \frac{105,560s}{(0.4s^2 + 10s + 5)(s^2 + 142,129)}$$

2.27

$$(a) \quad \begin{bmatrix} 5 & 0 & 2 \\ 2 & -2 & 5 \\ 4 & 5 & -3 \end{bmatrix}, \quad \begin{bmatrix} 5 & -2 & 2 \\ 6 & -2 & -5 \\ -4 & -7 & 3 \end{bmatrix}$$

$$(b) \quad \begin{bmatrix} 10 & 17 & -11 \\ 4 & 4 & -10 \\ 2 & 0 & -5 \end{bmatrix}, \quad \begin{bmatrix} 4 & -2 & 0 \\ -10 & -3 & -4 \\ 44 & -13 & 8 \end{bmatrix}$$

$$(c) \quad \begin{bmatrix} 10 & 4 & 2 \\ 17 & 4 & 0 \\ -11 & -10 & -5 \end{bmatrix}, \quad \begin{bmatrix} 10 & 4 & 2 \\ 17 & 4 & 0 \\ -11 & -10 & -5 \end{bmatrix}$$

$$(d) \quad -\frac{1}{112} \begin{bmatrix} -20 & 85 & -126 \\ 0 & -28 & 56 \\ -8 & 34 & -28 \end{bmatrix}, \quad \frac{1}{14} \begin{bmatrix} -30 & 14 & -12 \\ 3 & 0 & 4 \\ 5 & 0 & 2 \end{bmatrix}^T \times \frac{1}{-8} \begin{bmatrix} 0 & 0 & -4 \\ -2 & 0 & 5 \\ 4 & 8 & -6 \end{bmatrix}^T$$

(e) $\lambda_1 = 4, \quad \lambda_2 = -2, \quad \lambda_3 = 1$

$$\mathbf{X}_1 = \begin{bmatrix} 6 \\ 4 \\ -1 \end{bmatrix}, \quad \mathbf{X}_2 = \begin{bmatrix} 0 \\ 2 \\ 1 \end{bmatrix}, \quad \mathbf{X}_3 = \begin{bmatrix} 3 \\ 4 \\ -4 \end{bmatrix}$$

(f) $\begin{bmatrix} 4 & 0 & 0 \\ 0 & -2 & 0 \\ 0 & 0 & 1 \end{bmatrix}$

2.28 ~ 2.29 생략

Chapter 03

- 3.1 ④ 3.2 ① 3.3 ③ 3.4 ① 3.5 ②
- 3.6 ④ 3.7 ① 3.8 ③ 3.9 ② 3.10 ①
- 3.11 ④ 3.12 ③ 3.13 ③ 3.14 ② 3.15 ②
- 3.16 ① 3.17 ① 3.18 ② 3.19 ④ 3.20 ①
- 3.21 ③ 3.22 ③ 3.23 ① 3.24 ① 3.25 ③
- 3.26 ④ 3.27 ④ 3.28 ①

3.29 생략

3.30

(a) $G(s) = \frac{20}{s}$ (b) $y(t) = \frac{10}{\sqrt{2}} e^{-2t} (\sin 10t + \cos 10t), \quad G(s) = \frac{10}{\sqrt{2}} \left\{ \frac{s+12}{(s+2)^2 + 100} \right\}$

3.31

(a) 생략 (b) $M(s) = \frac{200s + 800}{s^4 + 17s^3 + 120s^2 + 460s + 800}$

3.32 $M(s) = \frac{50s^2 + 200s + 10}{s^4 + 9s^3 + 32s^2 + 52s}$

3.33 ~ 3.35 생략

Chapter 04

- 4.1 ② 4.2 ② 4.3 ① 4.4 ③ 4.5 ①
- 4.6 ③ 4.7 ③ 4.8 ② 4.9 ① 4.10 ③
- 4.11 ④ 4.12 ③ 4.13 ② 4.14 ① 4.15 ③
- 4.16 ① 4.17 ④ 4.18 ② 4.19 ③ 4.20 ②
- 4.21 ④

4.22

$$Z_1(s) = \frac{200 \times 10^3}{1 + 20 \times 10^3 s}, \quad Z_2(s) = \frac{10}{s} + 300 \times 10^3$$

$$G(s) = - \frac{30 \times 10^3 \left(s^2 + \frac{2.5}{30 \times 10^3} s + \frac{1}{600 \times 10^6} \right)}{s}$$

4.23

$$(a) \quad X_2(s) = \frac{2}{10s^2 + 2s} \times F(s), \quad G(s) = \frac{1}{s(5s + 1)}$$

$$(b) \quad \begin{bmatrix} \frac{d}{dt} x_2 \\ \frac{d}{dt} v \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 0 & -\frac{1}{5} \end{bmatrix} \begin{bmatrix} x_2 \\ v \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{1}{5} \end{bmatrix} f(t)$$

$$4.24 \quad G(s) = \frac{0.21}{s(s + 2.53)}$$

4.25

(a)

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \\ \dot{x}_4 \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & -80 & -68 & -16 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \end{bmatrix} r$$

$$y = [80 \ 228 \ 94 \ 12] \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix}$$

(b) 종속표준형의 상태방정식을 구할 수 없다.

(c)

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \\ \dot{x}_4 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & -2 & 0 & 0 \\ 0 & 0 & -4 & 0 \\ 0 & 0 & 0 & -10 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} + \begin{bmatrix} 1 \\ 3 \\ -2 \\ 10 \end{bmatrix} r$$

$$y = [1 \ 1 \ 1 \ 1] \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix}$$

(d)

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \\ \dot{x}_4 \end{bmatrix} = \begin{bmatrix} -16 & -68 & -80 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} + \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \end{bmatrix} r$$

$$y = [12 \ 94 \ 228 \ 80] \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix}$$

(e)

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \\ \dot{x}_4 \end{bmatrix} = \begin{bmatrix} -16 & 1 & 0 & 0 \\ -68 & 0 & 1 & 0 \\ -80 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} + \begin{bmatrix} 12 \\ 94 \\ 228 \\ 80 \end{bmatrix} r$$

$$y = \begin{bmatrix} 1 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix}$$

$$4.26 \quad \frac{9s^2 + 52s + 67}{s^3 + 9s^2 + 23s + 15}$$

4.27 ~ 4.28 생략

Chapter 05

5.1 ③	5.2 ④	5.3 ①	5.4 ②	5.5 ④
5.6 ④	5.7 ③	5.8 ③	5.9 ②	5.10 ①
5.11 ②	5.12 ④	5.13 ①	5.14 ④	5.15 ①
5.16 ②	5.17 ③	5.18 ②	5.19 ④	5.20 ④
5.21 ①	5.22 ④	5.23 ③	5.24 ①	5.25 ③
5.26 ①	5.27 ②	5.28 ③	5.29 ③	5.30 ②
5.31 ②	5.32 ①	5.33 ②		

5.34

$$e_o(t) = 100 - 11.7e^{-3.82t} + 1.71e^{-26.18t}$$

5.35

- $c(t) = 0.5 - 0.535e^{-5t}\sin(5\sqrt{7}t + 69.2^\circ)$
- 특성방정식의 근 : $s_1 = -5 + j5\sqrt{7}$, $s_2 = -5 - j5\sqrt{7}$
- 감쇠비 : $\zeta \approx 0.354$
- 고유주파수 : $\omega_n \approx 14.14$
- 첨두값시간 : $T_p \approx 0.24[\text{sec}]$
- 지연시간 : $T_d = 0.088[\text{sec}]$
- 상승시간 : $T_r = 0.12[\text{sec}]$
- 정정시간 : $T_s = 0.8[\text{sec}]$
- 백분율 오버슈트 : $\%OS = 30.45[\%]$

5.36

(a) $c(t) = 1 - 1.09e^{-4t} \sin(\sqrt{84}t + 66.4^\circ)$

(b) $c(t) = 1 - 0.83e^{-10t} - 0.999e^{-4t} \sin(\sqrt{84}t + 9.8^\circ)$

(c) $c(t) = 1 + 2.012e^{-4t} \sin(\sqrt{84}t - 29.8^\circ)$

5.37

(a) $y(t) = 1 + 18e^{-2t} - 11e^{-3t}$

(b) $y = 1 + 18e^{-2t} - 11e^{-3t}$

5.38

(a) $(s+2)^2(s+3) = 0$

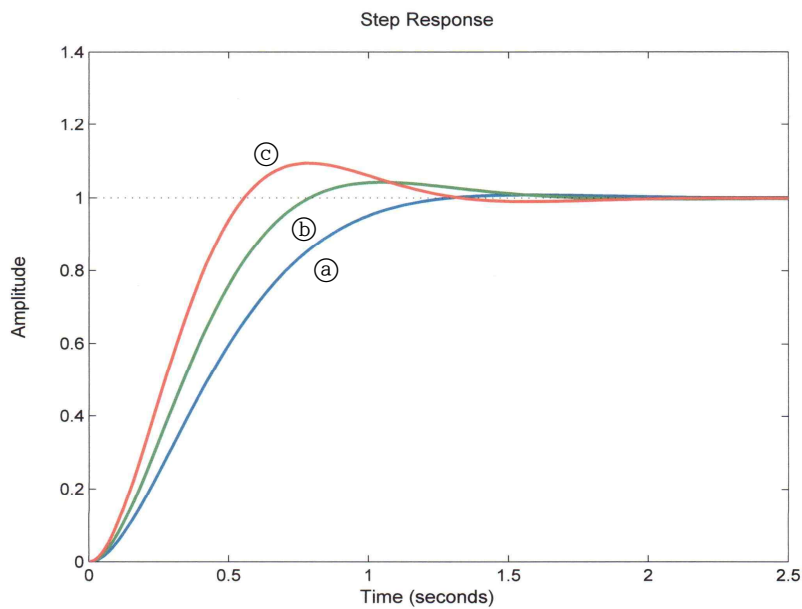
$$\therefore s_1 = -2, s_2 = -2, s_3 = -3$$

(b) $\Phi(t) = \begin{bmatrix} e^{-2t} & te^{-2t} & 0 \\ 0 & e^{-2t} & 0 \\ 0 & 0 & e^{-3t} \end{bmatrix}$

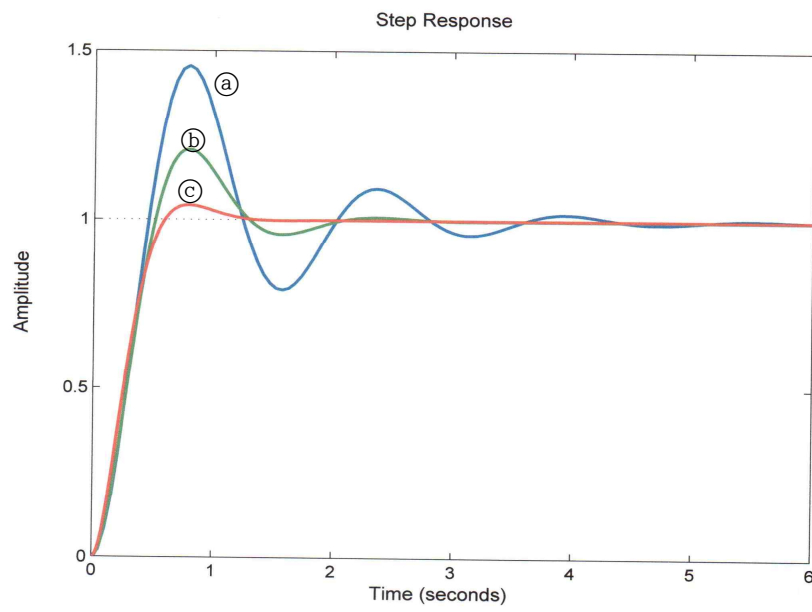
(c) $y(t) = \frac{25}{12} - \frac{3}{2}te^{-2t} - \frac{7}{4}e^{-2t} - \frac{1}{3}e^{-3t}$

(d) 생략

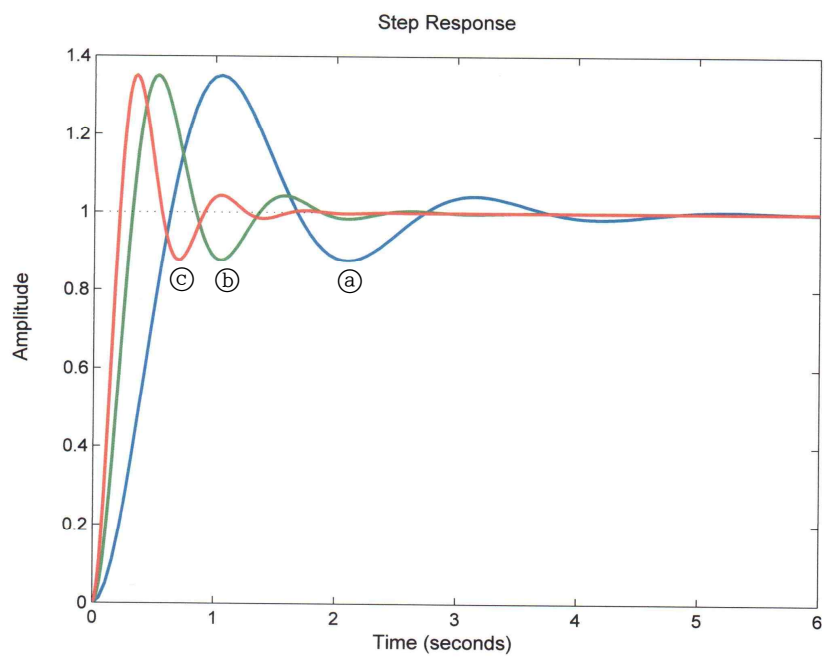
5.39



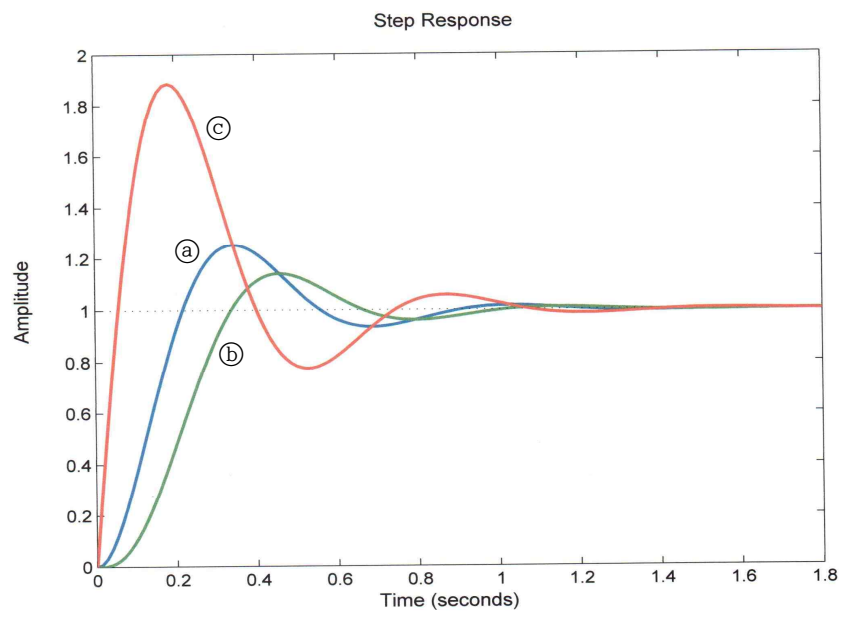
5.40



5.41



5.42



Chapter 06

6.1 ①	6.2 ②	6.3 ①	6.4 ③	6.5 ④
6.6 ④	6.7 ③	6.8 ①	6.9 ②	6.10 ③
6.11 ①	6.12 ①	6.13 ③	6.14 ②	6.15 ④
6.16 ②	6.17 ④	6.18 ③	6.19 ②	6.20 ②
6.21 ④	6.22 ①	6.23 ③	6.24 ①	6.25 ②
6.26 ②	6.27 ③	6.28 ①	6.29 ④	6.30 ②
6.31 ①	6.32 ②	6.33 ②	6.34 ①	6.35 ④
6.36 ③	6.37 ③	6.38 ④	6.39 ④	6.40 ①

6.41 불안정

6.42 불안정

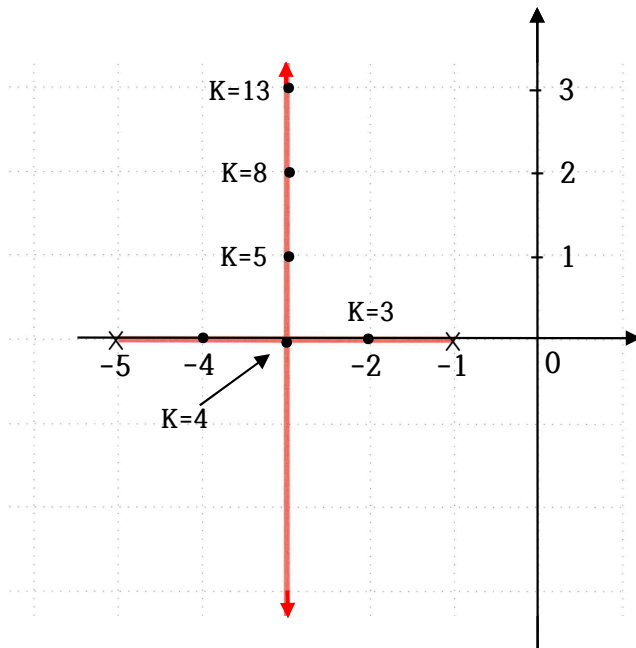
6.43 $K_p = \infty$, $K_v = 4$, $K_a = 0$
 $e_{step}(\infty) = 0$, $e_{ramp}(\infty) = 0.25$, $e_{parabola}(\infty) = \infty$

6.44 불안정

Chapter 07

- 7.1 ② 7.2 ② 7.3 ③ 7.4 ④ 7.5 ④
- 7.6 ② 7.7 ④ 7.8 ③ 7.9 ① 7.10 ②
- 7.11 ① 7.12 ① 7.13 ④ 7.14 ② 7.15 ③
- 7.16 ② 7.17 ① 7.18 ④ 7.19 ④

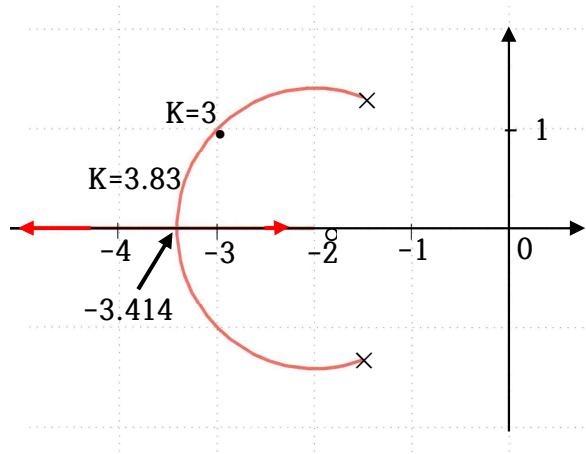
7.20



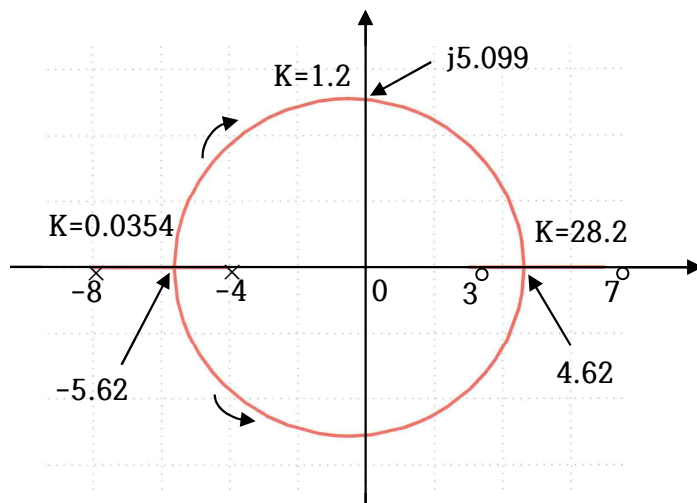
7.21

(b)와 (c)는 특성방정식의 근이 될 수 있고, 그때의 K 값은 각각 3과 13이다.

7.22



7.23



$K < 1.2$

7.24

$K < 40$

$$c(t) = \frac{4}{9} - \frac{2}{9}e^{-3t} - \frac{2}{3}e^{-t}\sin(\sqrt{2}t + 19.47^\circ)$$

7.25 생략

Chapter 08

8.1 ④

8.2 ③

8.3 ②

8.4 ①

8.5 ①

8.6 ④

8.7 ②

8.8 ③

8.9 ②

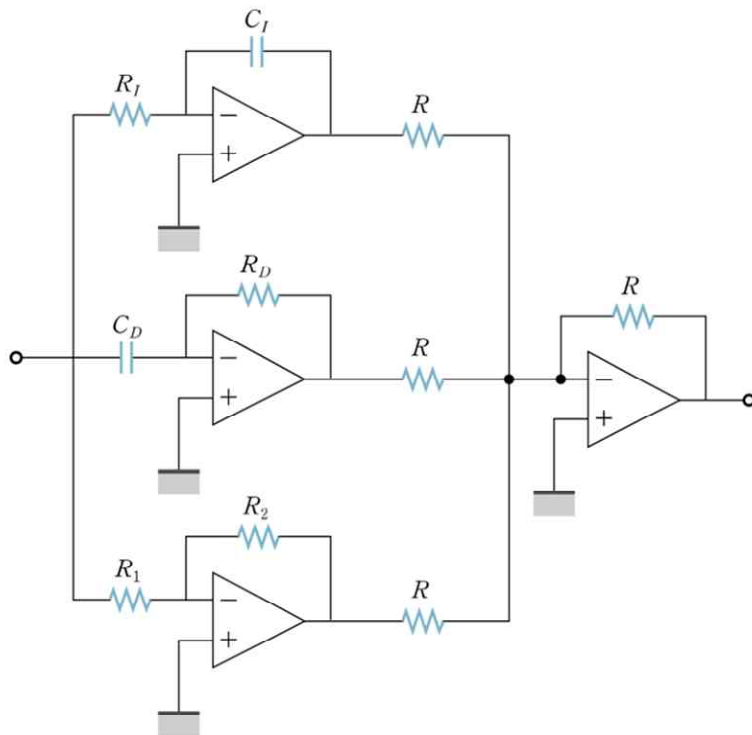
8.10 ③

8.11 ④

8.12 $K \doteq 0.72$

$$8.13 \quad G_c(s) = \frac{4.86(s+7.85)(s+0.1)}{s}$$

8.14



$$K_P = \frac{R_2}{R_1}, \quad K_D = R_D C_D, \quad K_I = \frac{1}{R_I C_I}$$

8.15 생략

Chapter 09

- 9.1 ② 9.2 ① 9.3 ④ 9.4 ③ 9.5 ②
- 9.6 ④ 9.7 ② 9.8 ④ 9.9 ② 9.10 ②
- 9.11 ① 9.12 ③ 9.13 ④ 9.14 ① 9.15 ②
- 9.16 ③ 9.17 ② 9.18 ② 9.19 ③ 9.20 ①
- 9.21 ① 9.22 ④ 9.23 ① 9.24 ③ 9.25 ④
- 9.26 ④

9.27 생략

9.28

(a) 진폭비 = $\frac{20}{40} = 0.5$, 위상차 = -210°

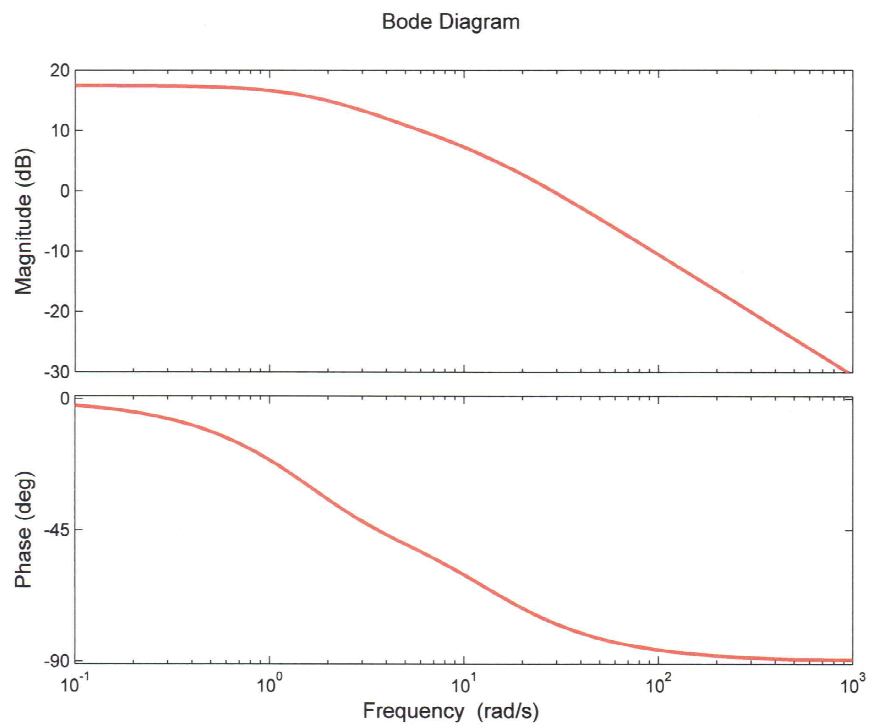
(b)

진폭비 = $\frac{40}{100} = 0.4$, 위상차 = $-10^\circ - 45^\circ = -55^\circ$

(c)

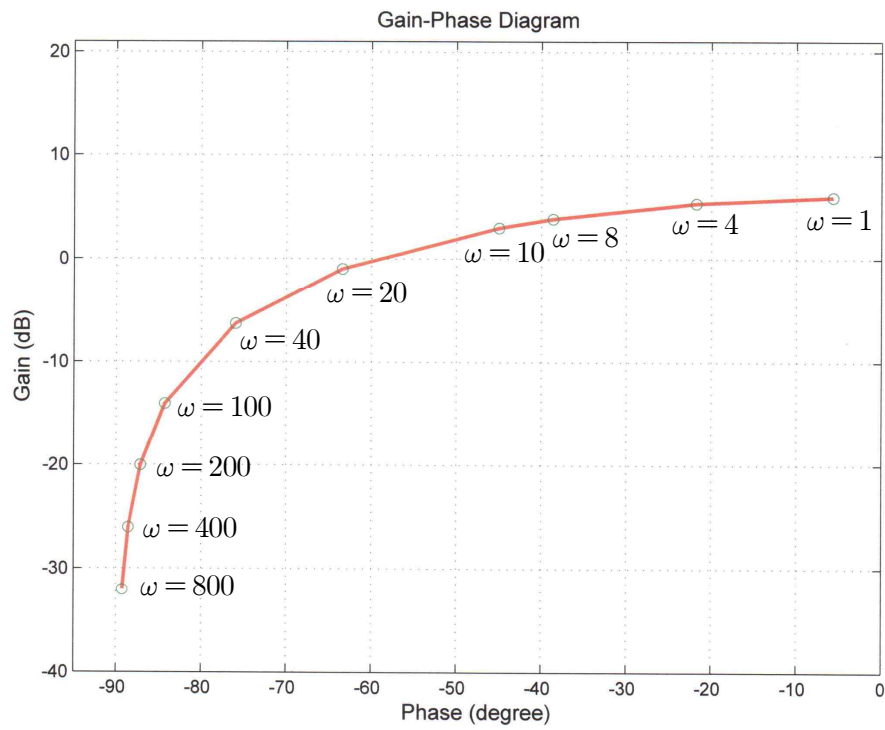
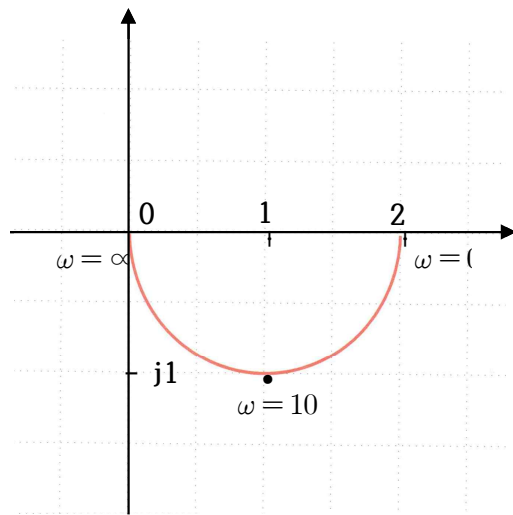
진폭비 = $\frac{5}{20} = 0.25$, 위상차 = -36.87°

9.29

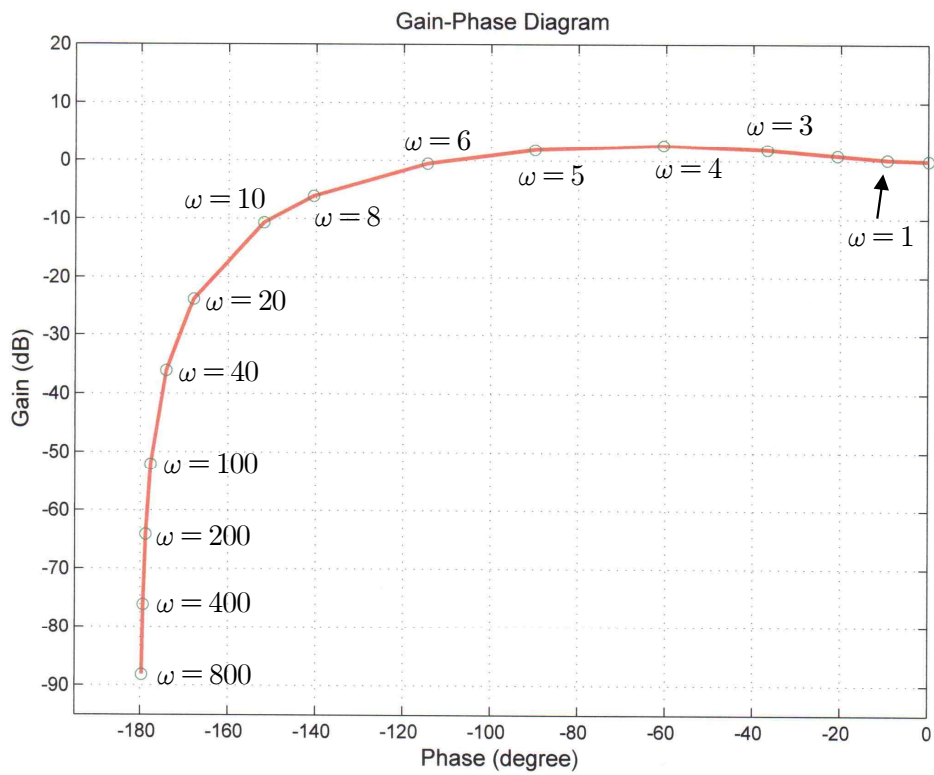
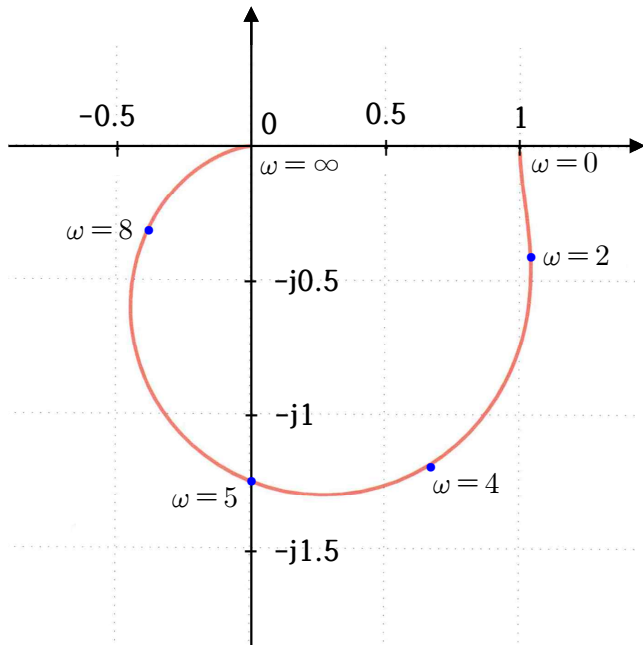


9.30

(a)



(b)



9.31 생략

Chapter 10

- 10.1 ④ 10.2 ③ 10.3 ① 10.4 ② 10.5 ①
- 10.6 ② 10.7 ③ 10.8 ④ 10.9 ① 10.10 ④
- 10.11 ③ 10.12 ② 10.13 ③ 10.14 ① 10.15 ②
- 10.16 ① 10.17 ④ 10.18 ① 10.19 ④ 10.20 ④

10.21 생략

10.22 $G_M = 13.6[\text{dB}]$, $\Phi_M = 47.0^\circ$

10.23

(a) $\omega_{GM} = \infty$, $G_M = \infty$, $\omega_{\Phi M} = 4.6[\text{rad/sec}]$, $\Phi_M = 33.3^\circ$

(b) $M_p = 4.8[\text{dB}]$, $\omega_r = 4.6[\text{rad/sec}]$, $\omega_{BW} = 7.6[\text{rad/sec}]$

(c) $T_s \doteq 2.54[\text{sec}]$, $T_r \doteq 0.3[\text{sec}]$, $T_p \doteq 0.63[\text{sec}]$, $\%OS = 37.2[\%]$

10.23 생략

Chapter 11

- 11.1 ① 11.2 ② 11.3 ② 11.4 ④ 11.5 ③
- 11.6 ① 11.7 ② 11.8 ④ 11.9 ③ 11.10 ①
- 11.11 ④ 11.12 ② 11.13 ③ 11.14 ④

11.15

- (a) 50 [%]
 (b) $K=19$
 (c) 시스템이 불안정해진다.
 (d) $G_{lag}(s) = \frac{s+0.19}{s+0.01}$

11.16

- (a) 1.68
 (b) $T_s \approx 8.187[\text{sec}]$

11.17

- (a) 2.3 [%]
 (b) $G_{lead}(s) = \frac{58}{27} \times \frac{s+27}{s+58}$
 (c) $T_p \approx 0.07[\text{sec}]$
 (d) $T_s = 0.22[\text{sec}]$, $T_r = 0.03[\text{sec}]$, $T_p = 0.08[\text{sec}]$, $\%OS = 25.9[\%]$

11.18

- (a) $G_c(s) = 237 \times \frac{(s+0.19)(s+2.32)}{(s+0.03)(s+232)}$
 (b) ~ (c) 생략

11.19 ~ 11.20 생략

Chapter 12

12.1 ③ 12.2 ② 12.3 ① 12.4 ③ 12.5 ②

12.6 ④ 12.7 ③

12.8 $k_1 = 12, k_2 = 6$

12.9 $k_1 = 23, k_2 = 185.8, k_3 = 836$

12.10 $k_1 = 13, k_2 = -5, k_3 = -2$

12.11 $q_1 = 3.6, q_2 = 84.6$

12.12 $q_1 = 81, q_2 = 1980, q_3 = 11988$

12.13 $q_1 = 1.8, q_2 = 58.25, q_3 = -41$

12.14 $q_1 = -189.5, q_2 = 1521.5, q_3 = -11774.7$

12.15 생략

Chapter 13

- 13.1 ④ 13.2 ④ 13.3 ③ 13.4 ② 13.5 ③
- 13.6 ① 13.7 ① 13.8 ③ 13.9 ② 13.10 ④
- 13.11 ④ 13.12 ③ 13.13 ① 13.14 ② 13.15 ③
- 13.16 ①

$$13.17 \quad X(z) = T^2 \left\{ \frac{z(z+1)}{(z-1)^3} \right\}$$

$$13.18 \quad X(z) = \mathcal{Z} [\sin \omega t] = \frac{(\sin \omega T) z}{z^2 - (2 \cos \omega T) z + 1}$$

$$13.19 \quad X(z) = \mathcal{Z} \left[a^{\frac{t}{T}} \right] = \frac{z}{z-a} \quad \text{단, } t = kT, \quad k = 0, 1, 2, 3, 4, 5, \dots \text{이다.}$$