Facultad de Informática

Control Industrial

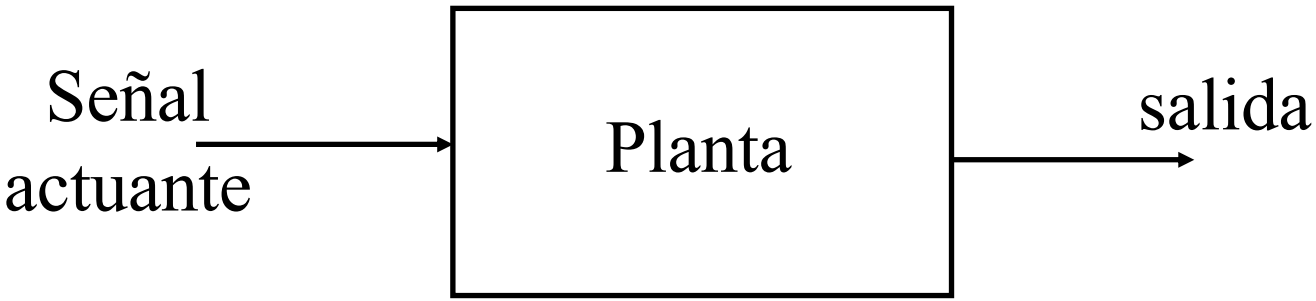
Sistemas de control en lazo cerrado

Curso 2007-08

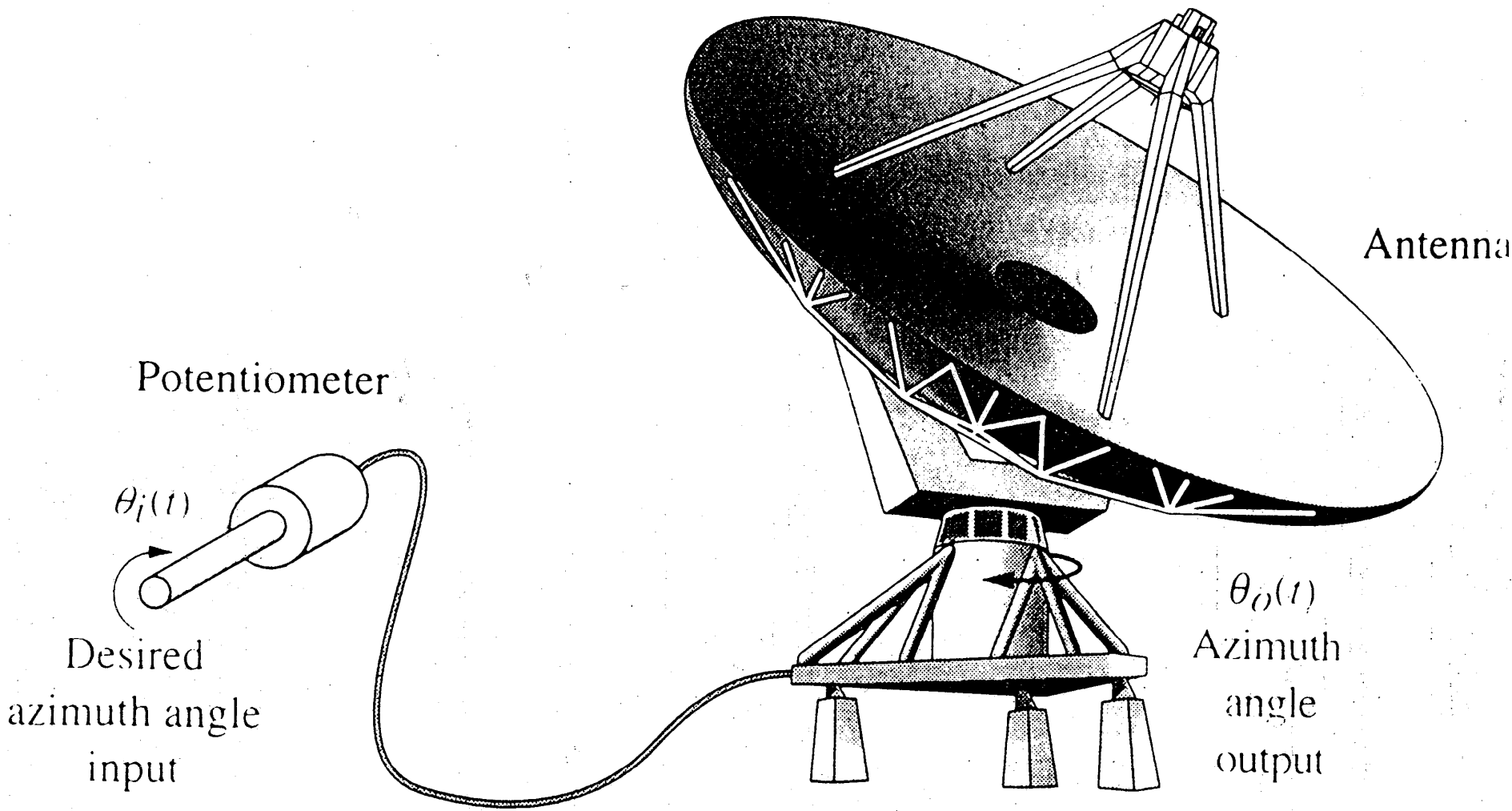
Conceptos básicos

- Planta: cualquier objeto físico cuya respuesta se desea controlar

- Las plantas se pueden representar por sistemas

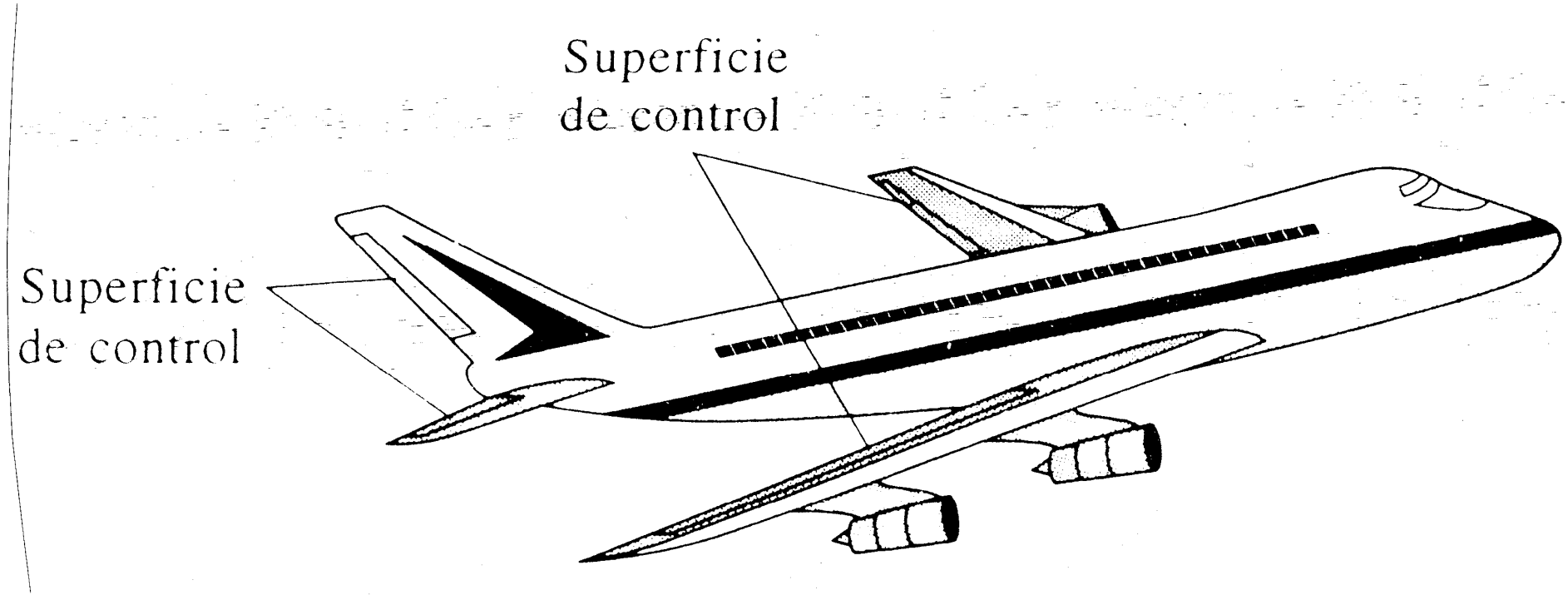


Ejemplo de planta



Fuente: Norman S. Nise, Control Systems Engineering, p. 18, Ed. John Wiley & Sons, 2000.

Ejemplo de planta (II)



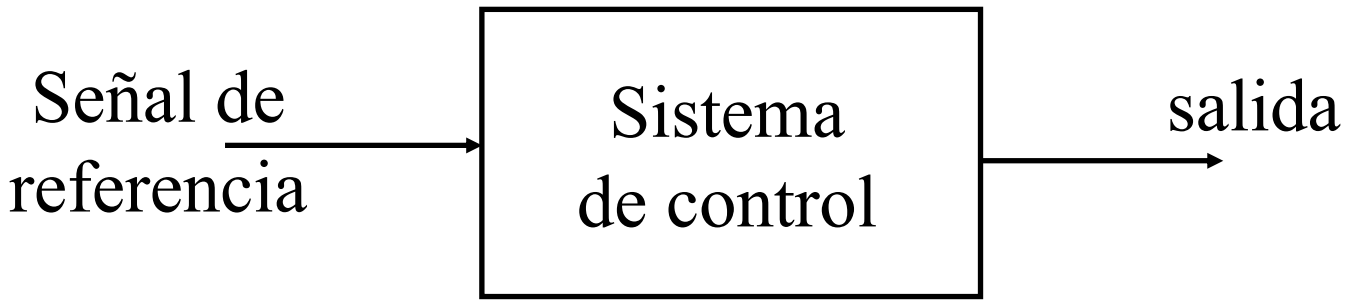
Fuente: Benjamin C. Kuo, Sistemas de Control Automático, p. 403, Ed. Prentice-Hall, 1995.

Ejemplo de planta (III)

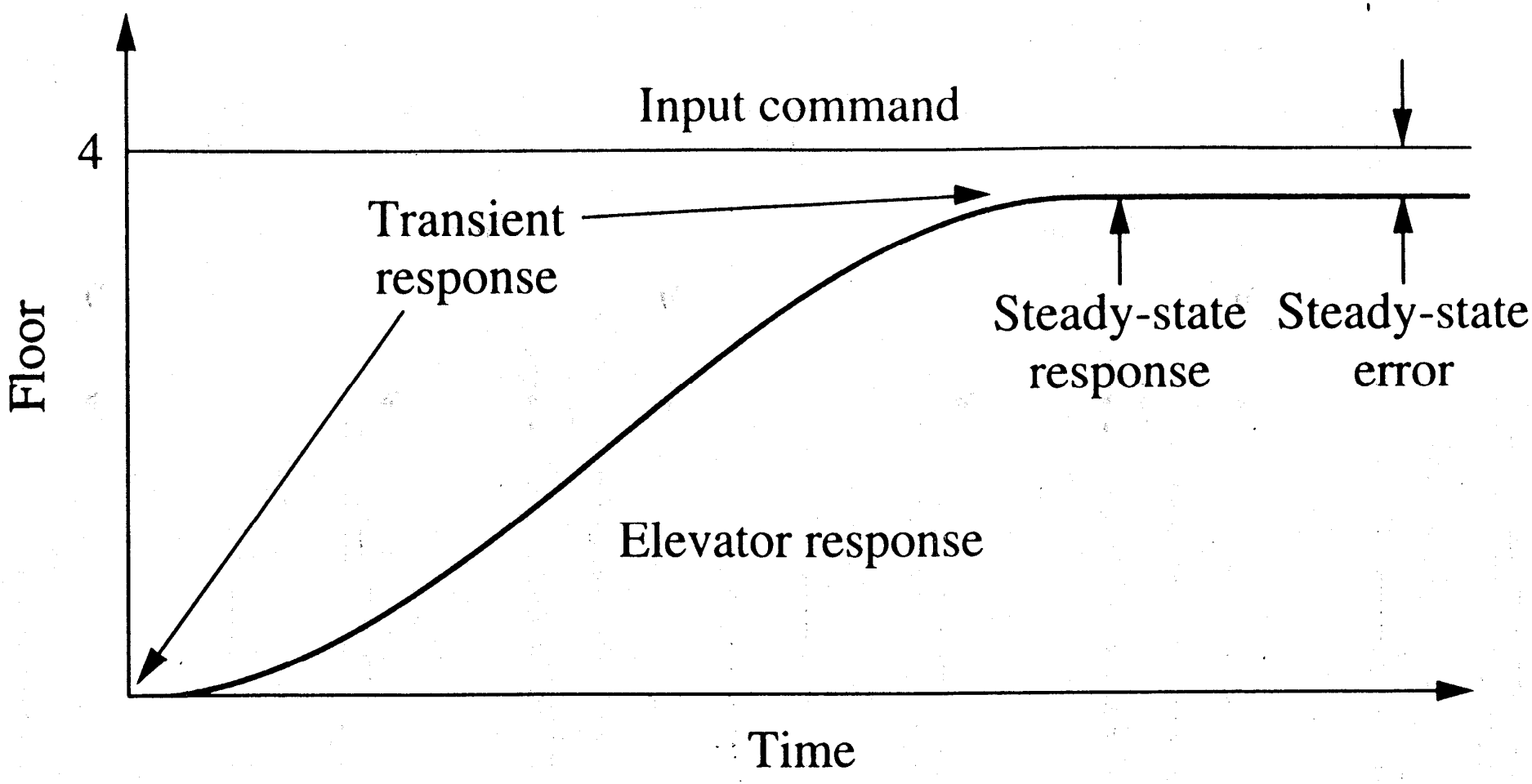
Fuente: Benjamin C. Kuo, Sistemas de Control Automático, p. 4, Ed. Prentice-Hall, 1995.

Conceptos básicos

- Sistema de control: conjunto de subsistemas y plantas interconectados con la intención de controlar las salidas de las plantas, i.e., que las salidas de las plantas sigan unos objetivos prefijados.



Respuesta típica de un sistema de control

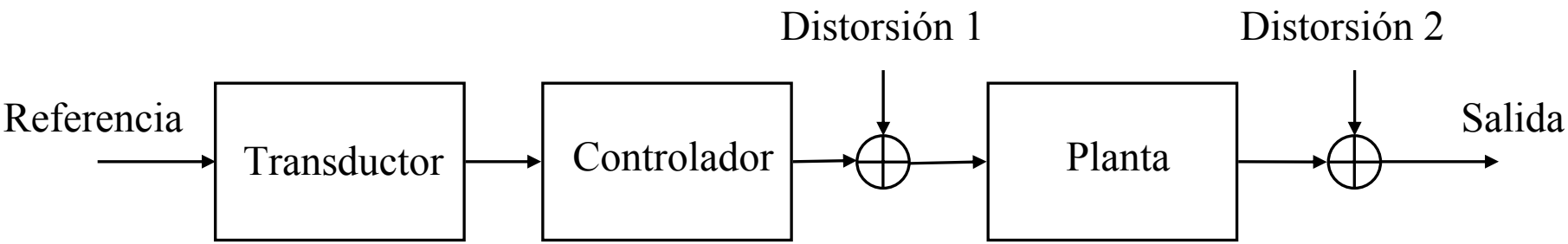


Fuente: Norman S. Nise, Control Systems Engineering, p. 11, Ed. John Wiley & Sons, 2000.

Objetivos de diseño de un sistema de control

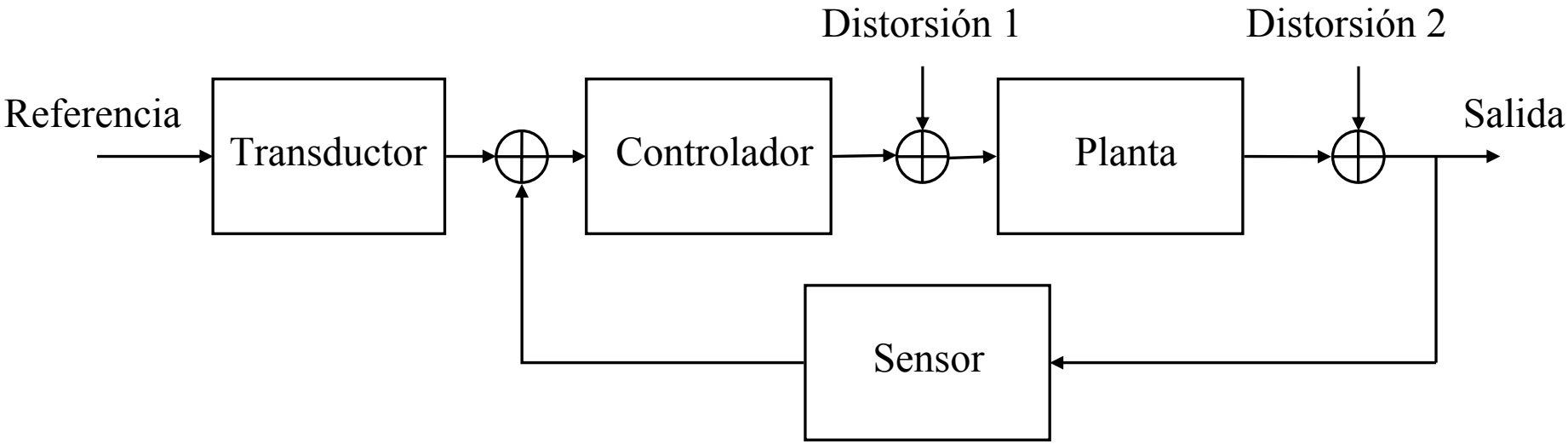
- Cumplir unas especificaciones de respuesta transitoria.
- Cumplir unas especificaciones de respuesta en estado estable.
- Garantizar la estabilidad.
- Robustez.
- Consideraciones de tipo económico.

Sistemas de control en lazo abierto



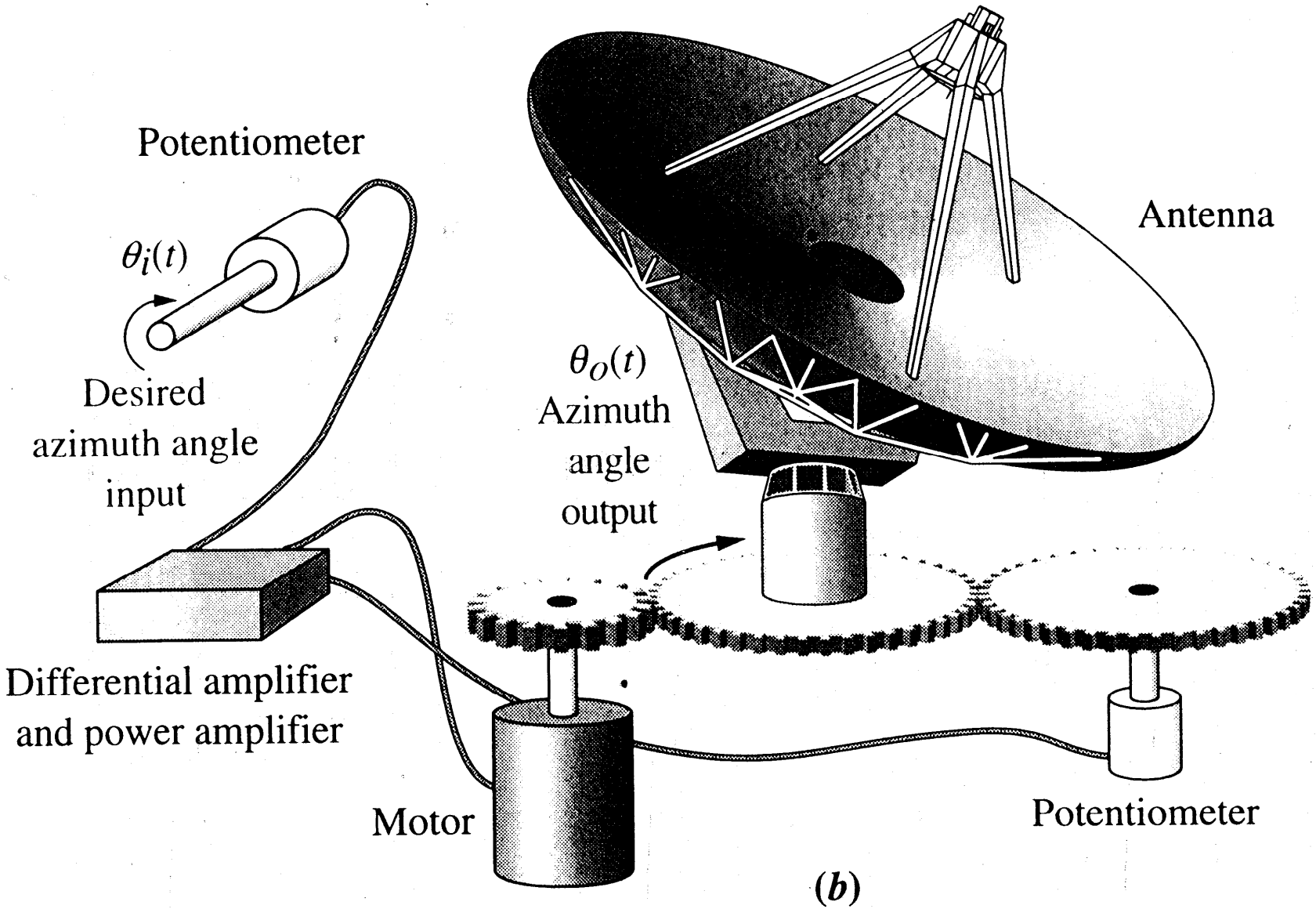
- Sistemas de control extraordinariamente sencillos ☺
- Necesita una perfecta calibración de la planta
- No puede compensar posibles distorsiones en el sistema

Sistemas de control en lazo cerrado



- Mayor robustez frente a imperfecciones en la caracterización de las plantas
- Permite compensar las distorsiones
- Las respuestas transitoria y permanente se pueden controlar más convenientemente y con mayor flexibilidad
- Es más complejo y caro que el control en lazo abierto.

Ejemplo de sistema de control en lazo cerrado



Fuente: Norman S. Nise, Control Systems Engineering, p. 18, Ed. John Wiley & Sons, 2000.

Ejemplo sistema de control en lazo cerrado (II)

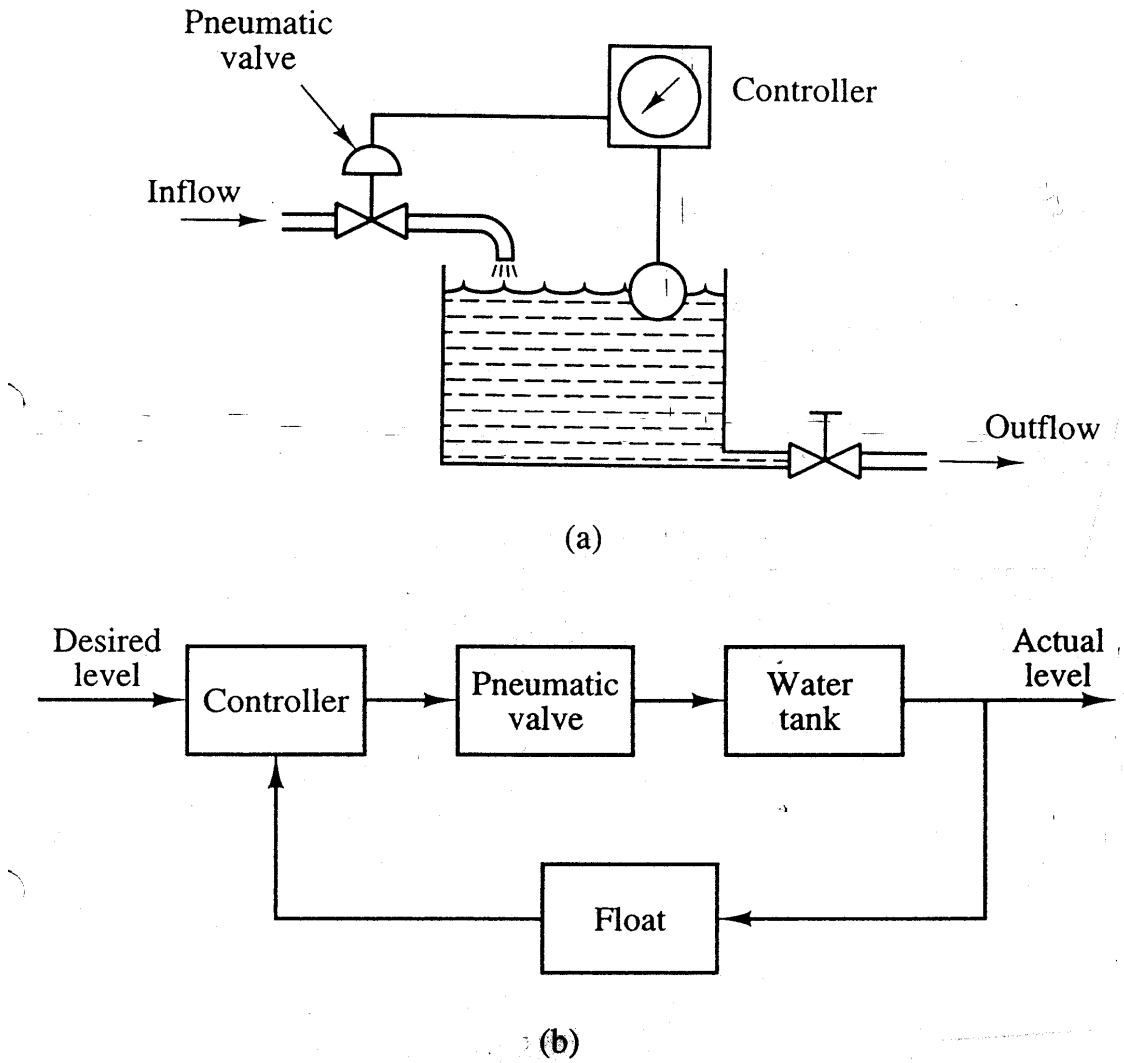
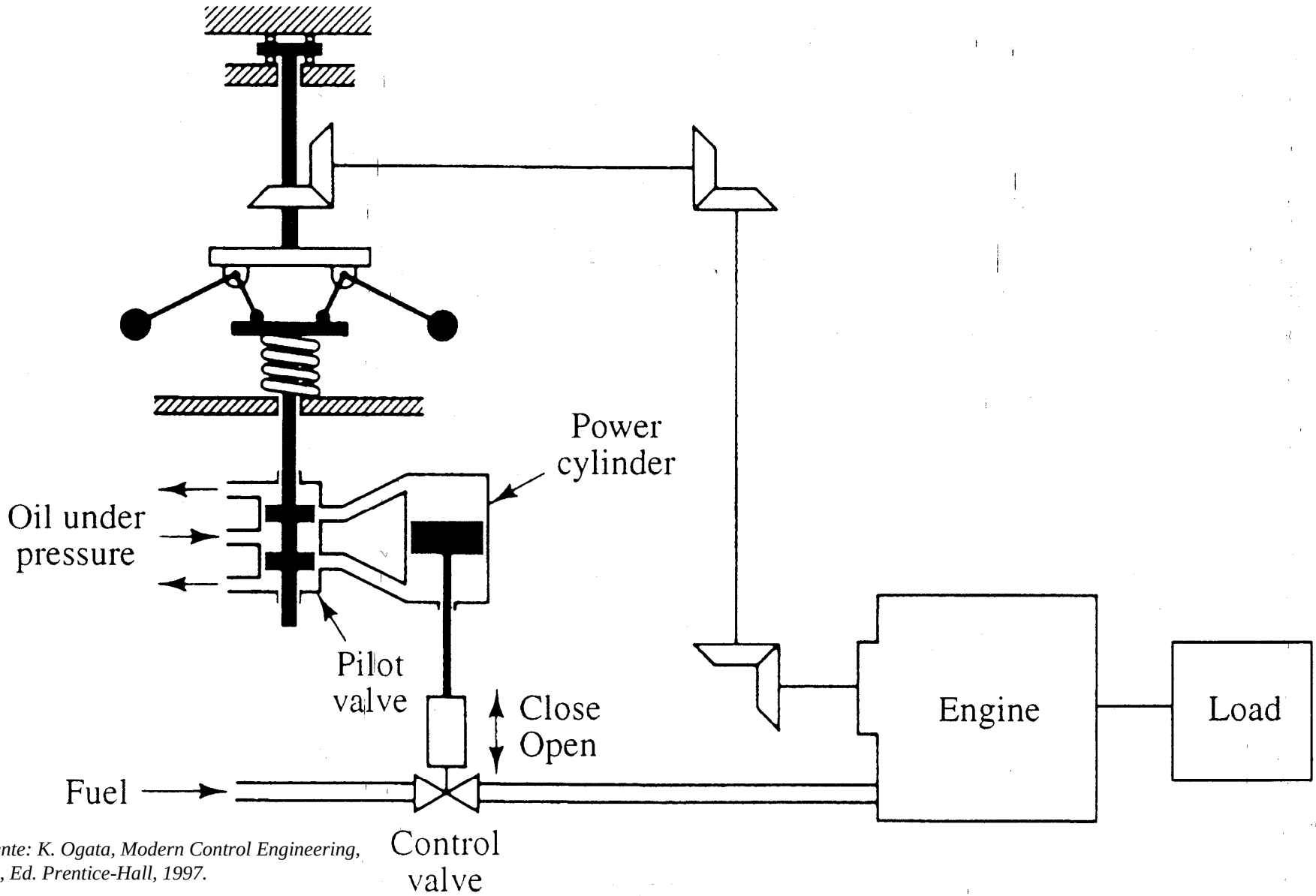


Figure 1–5
(a) Liquid-level control system; (b) block diagram.

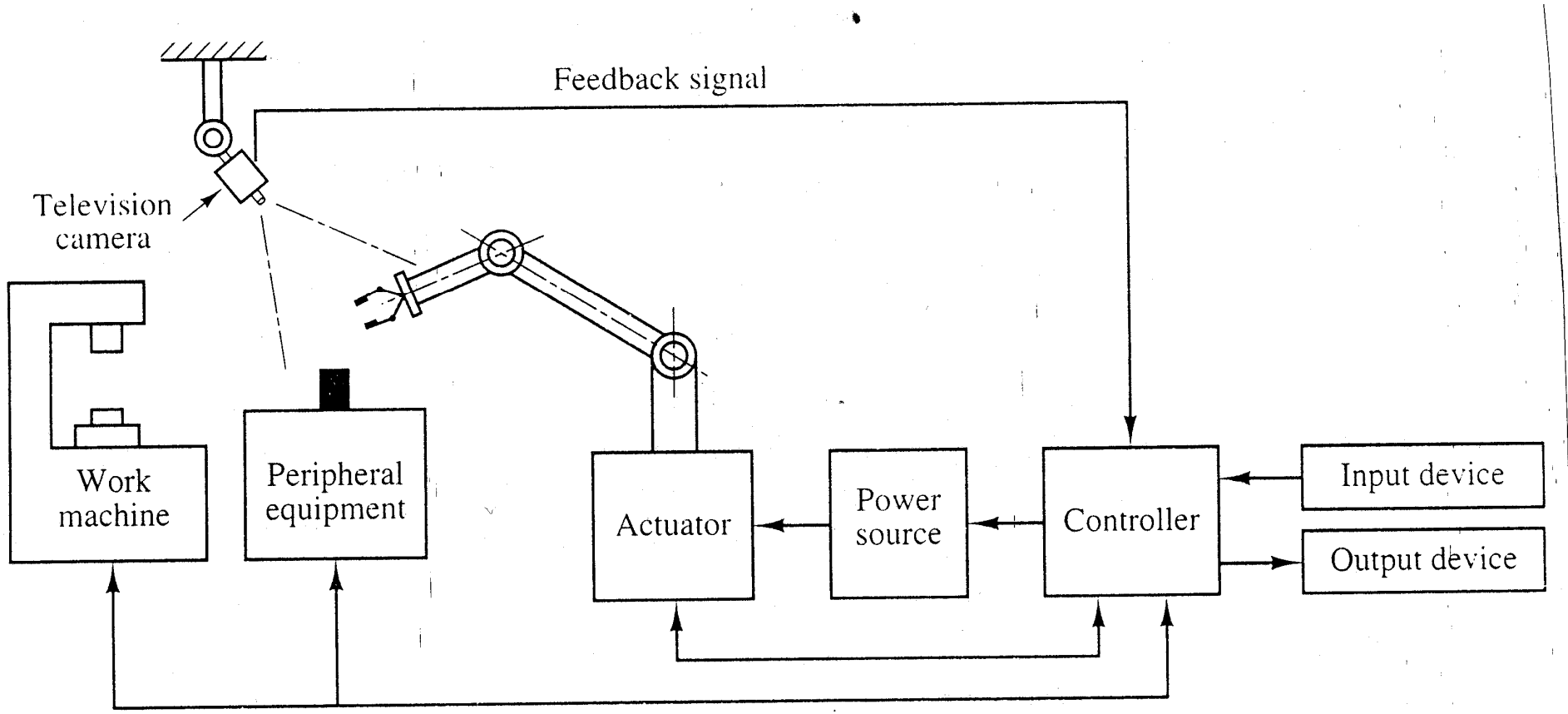
Fuente: K. Ogata, Modern Control Engineering, p. 10, Ed. Prentice-Hall, 1997.

Ejemplo de sistema de control en lazo cerrado (III)



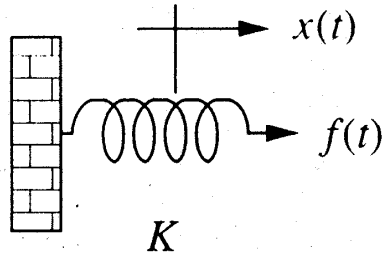
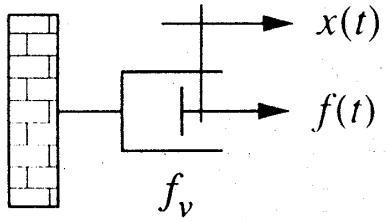
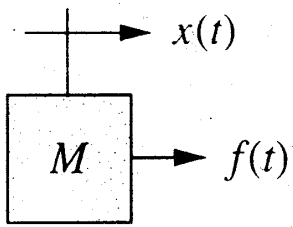
Fuente: K. Ogata, Modern Control Engineering, p. 3, Ed. Prentice-Hall, 1997.

Ejemplo de sistema de control en lazo cerrado (IV)



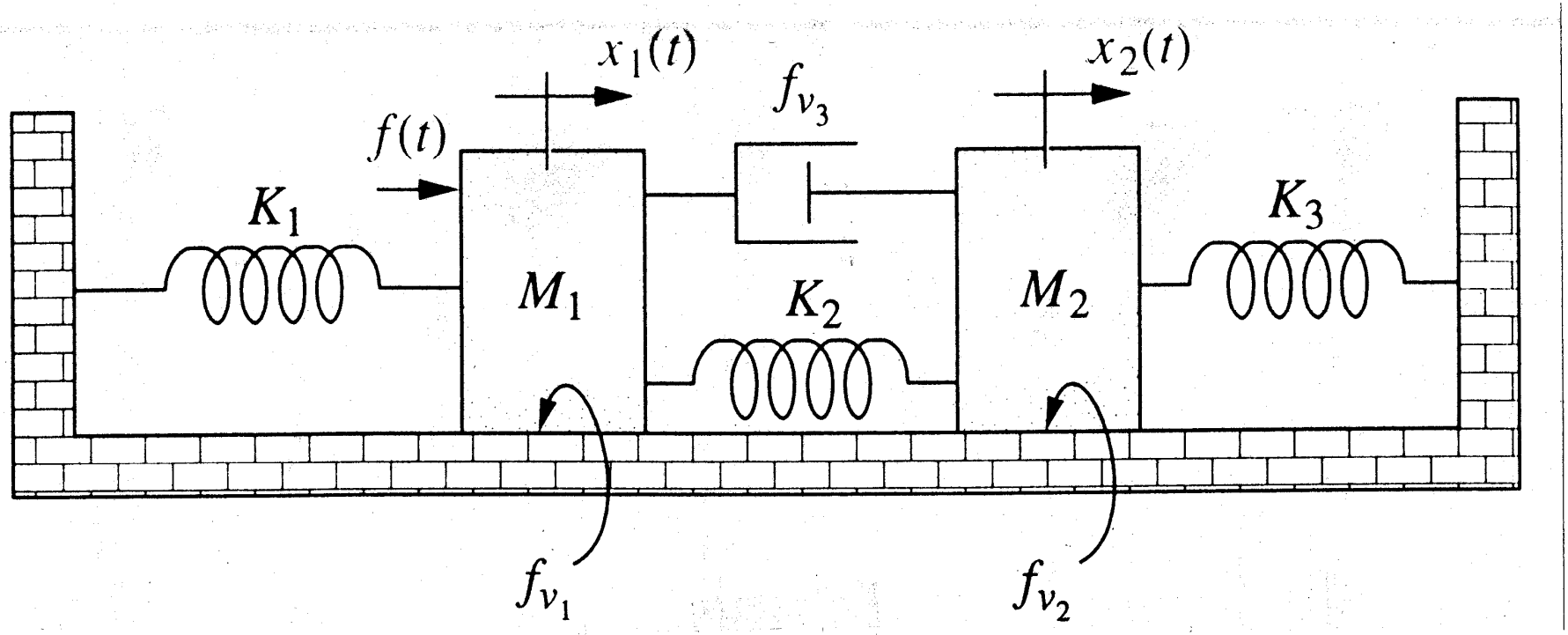
Fuente: K. Ogata, Modern Control Engineering, p. 5, Ed. Prentice-Hall, 1997.

Elementos de un sistema mecánico traslacional

Component	Force-velocity	Force-displacement
Spring 	$f(t) = K\int_0^t v(\tau)\,d\tau$	$f(t) = Kx(t)$
Viscous damper 	$f(t) = f_v v(t)$	$f(t) = f_v \frac{dx(t)}{dt}$
Mass 	$f(t) = M\frac{dv(t)}{dt}$	$f(t) = M\frac{d^2x(t)}{dt^2}$

Fuente: Norman S. Nise, Control Systems Engineering, p. 69, Ed. John Wiley & Sons, 2000.

Ejemplo de sistema mecánico traslacional



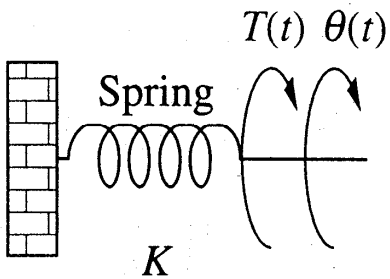
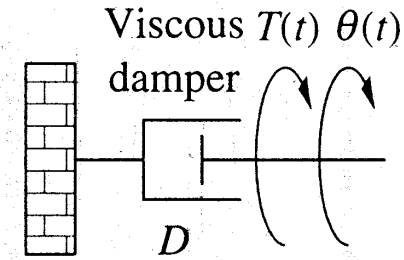
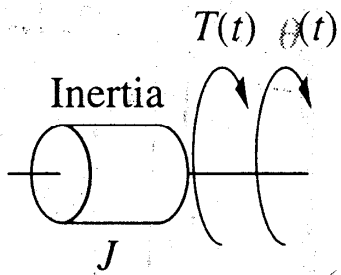
$$M_1 M_2 \frac{d^4 x_2(t)}{dt^4} + \left[M_1(B_2+B_3) + M_2(B_1+B_3)\right]\frac{d^3 x_2(t)}{dt^3} + \left[M_1(k_2+k_3) + M_2(k_1+k_2) + (B_1+B_3)(B_2+B_3) - B_3^2\right]\frac{d^2 x_2(t)}{dt^2} +$$

$$+ \left[(k_1+k_2)(B_2+B_3) + (k_2+k_3)(B_1+B_3) - 2k_2 B_3\right]\frac{dx_2(t)}{dt} + \left[(k_1+k_2)(k_2+k_3) - k_2^2\right] x_2(t) =$$

$$= B_3 \frac{df(t)}{dt} + k_2 f(t)$$

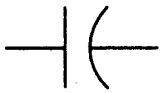
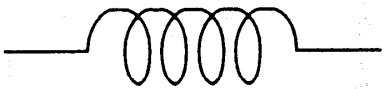
Fuente: Norman S. Nise, Control Systems Engineering, p. 72, Ed. John Wiley & Sons, 2000.

Elementos de un sistema mecánico rotacional

Component	Torque-angular velocity	Torque-angular displacement
	$T(t) = K\int_0^t \omega(\tau)\,d\tau$	$T(t) = K\theta(t)$
	$T(t) = D\omega(t)$	$T(t) = D\dfrac{d\theta(t)}{dt}$
	$T(t) = J\dfrac{d\omega(t)}{dt}$	$T(t) = J\dfrac{d^2\theta(t)}{dt^2}$

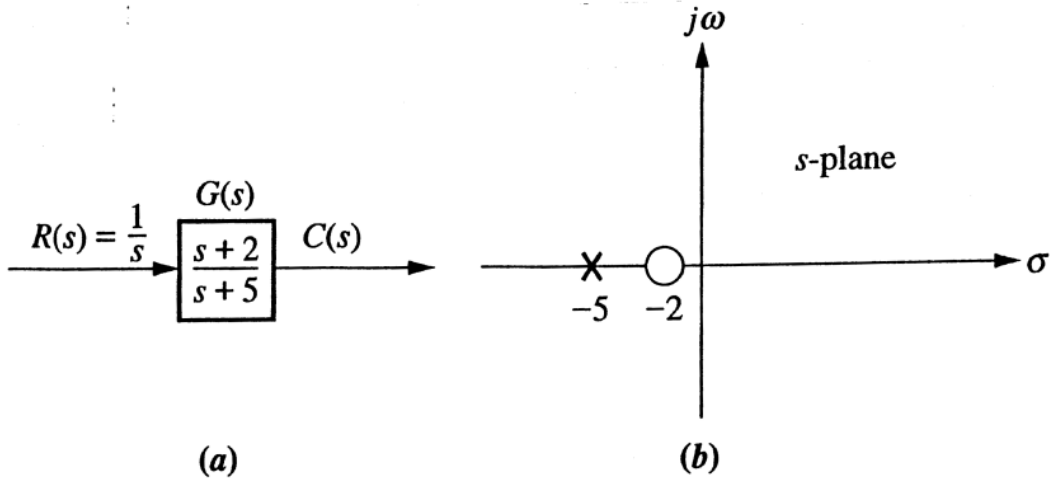
Fuente: Norman S. Nise, Control Systems Engineering, p. 77, Ed. John Wiley & Sons, 2000.

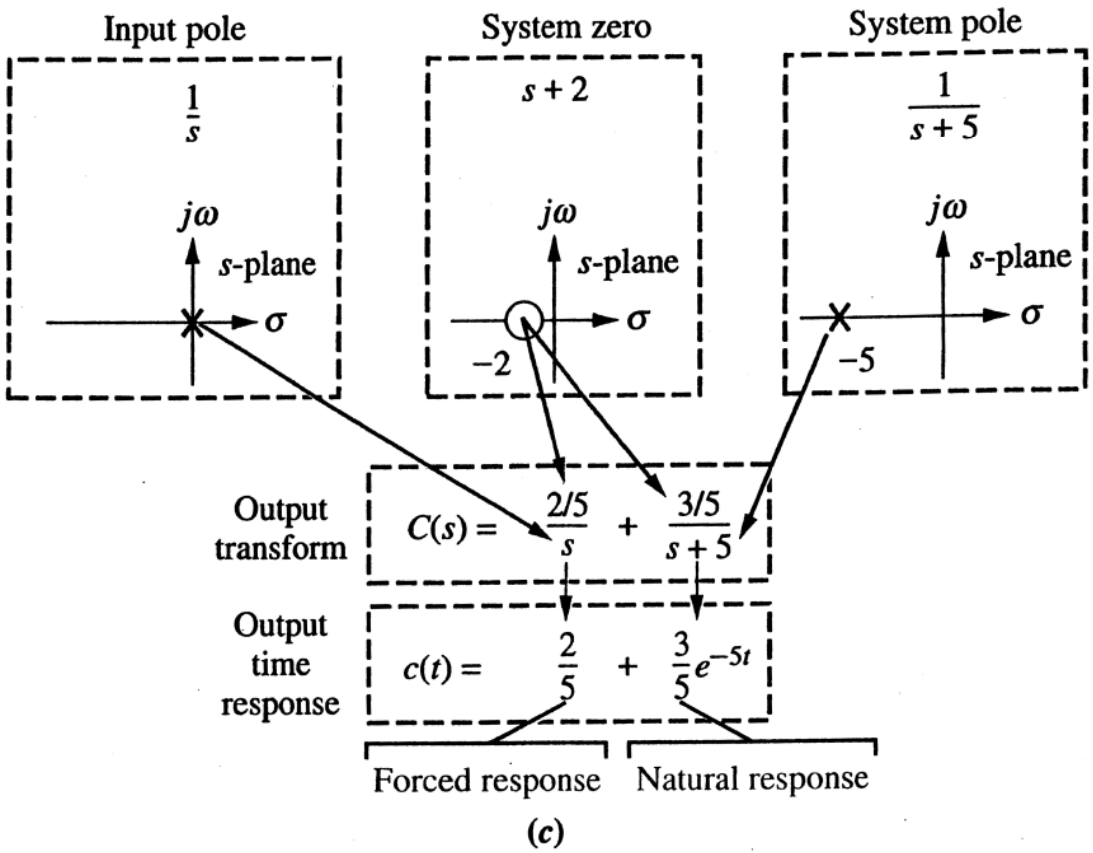
Elementos de un sistema eléctrico

Component	Voltage-current	Current-voltage	Voltage-charge
 Capacitor	$v(t) = \frac{1}{C}\int_0^t i(\tau)\,d\tau$	$i(t) = C\frac{dv(t)}{dt}$	$v(t) = \frac{1}{C}q(t)$
Resistor	$v(t) = Ri(t)$	$i(t) = \frac{1}{R}v(t)$	$v(t) = R\frac{dq(t)}{dt}$
 Inductor	$v(t) = L\frac{di(t)}{dt}$	$i(t) = \frac{1}{L}\int_0^t v(\tau)d\tau$	$v(t) = L\frac{d^2q(t)}{dt^2}$

Fuente: Norman S. Nise, Control Systems Engineering, p. 52, Ed. John Wiley & Sons, 2000.

Respuesta natural y forzada de un sistema

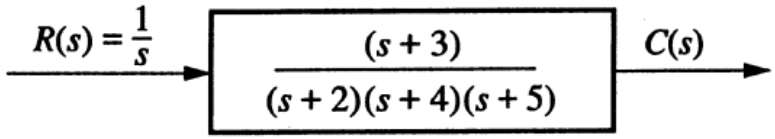




Respuesta natural y estabilidad de un sistema

Evaluating response using poles

Problem Given the system of Figure 4.3, write the output, $c(t)$, in general terms. Specify the forced and natural parts of the solution.



Solution By inspection, each system pole generates an exponential as part of the natural response. The input's pole generates the forced response. Thus,

$$C(s) \equiv \underbrace{\frac{K_1}{s}}_{\text{Forced response}} + \underbrace{\frac{K_2}{(s+2)} + \frac{K_3}{(s+4)} + \frac{K_4}{(s+5)}}_{\text{Natural response}} \tag{4.3}$$

Taking the inverse Laplace transform, we get

$$c(t) \equiv \underbrace{K_1}_{\text{Forced response}} + \underbrace{K_2 e^{-2t} + K_3 e^{-4t} + K_4 e^{-5t}}_{\text{Natural response}} \tag{4.4}$$

Respuesta al escalón de un sistema de orden 1

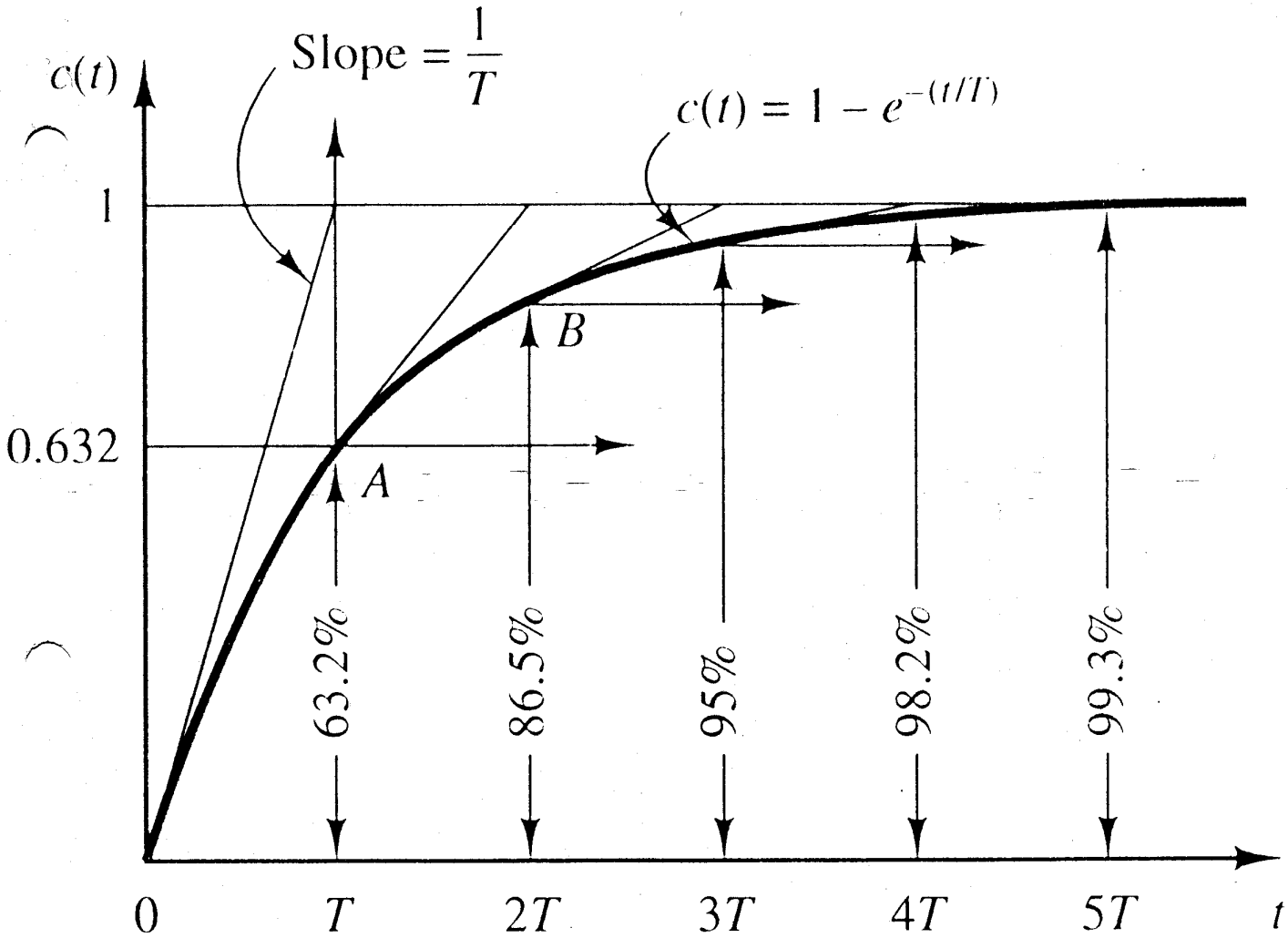
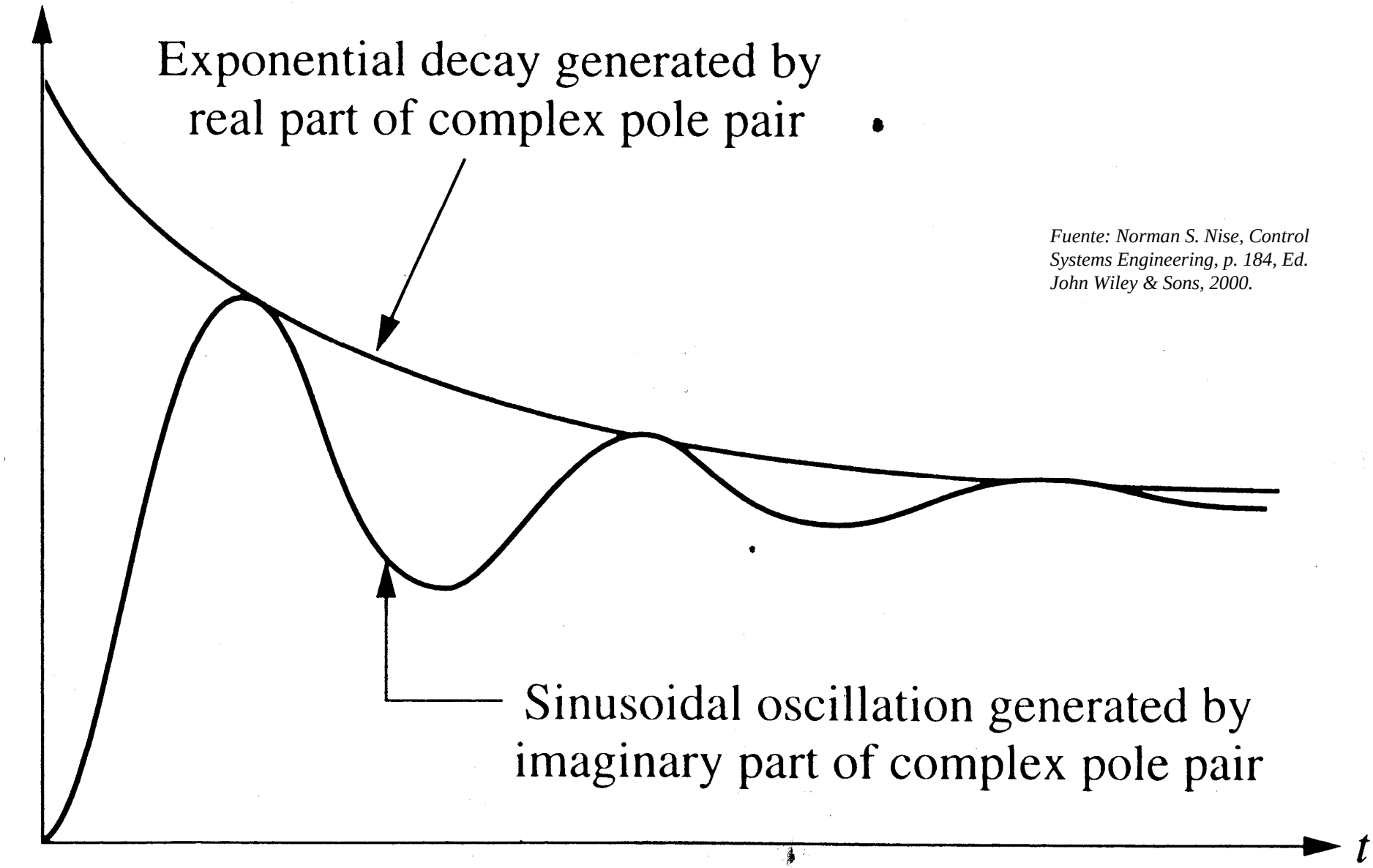


Figure 4–2
Exponential response curve.

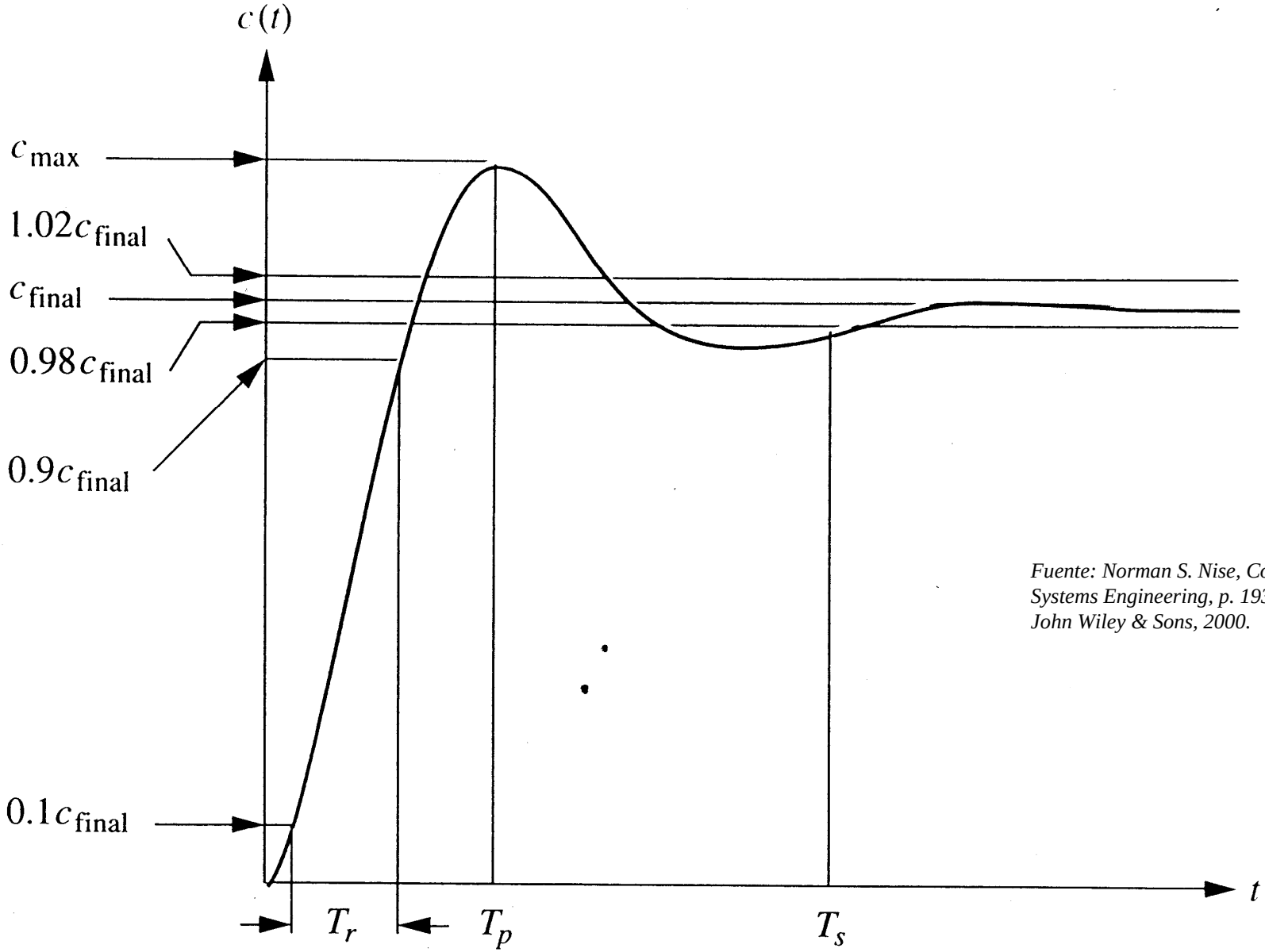
Fuente: K. Ogata, Modern Control Engineering, p. 137, Ed. Prentice-Hall, 1997.

Respuesta al escalón de un sistema de orden 2 subamortiguado

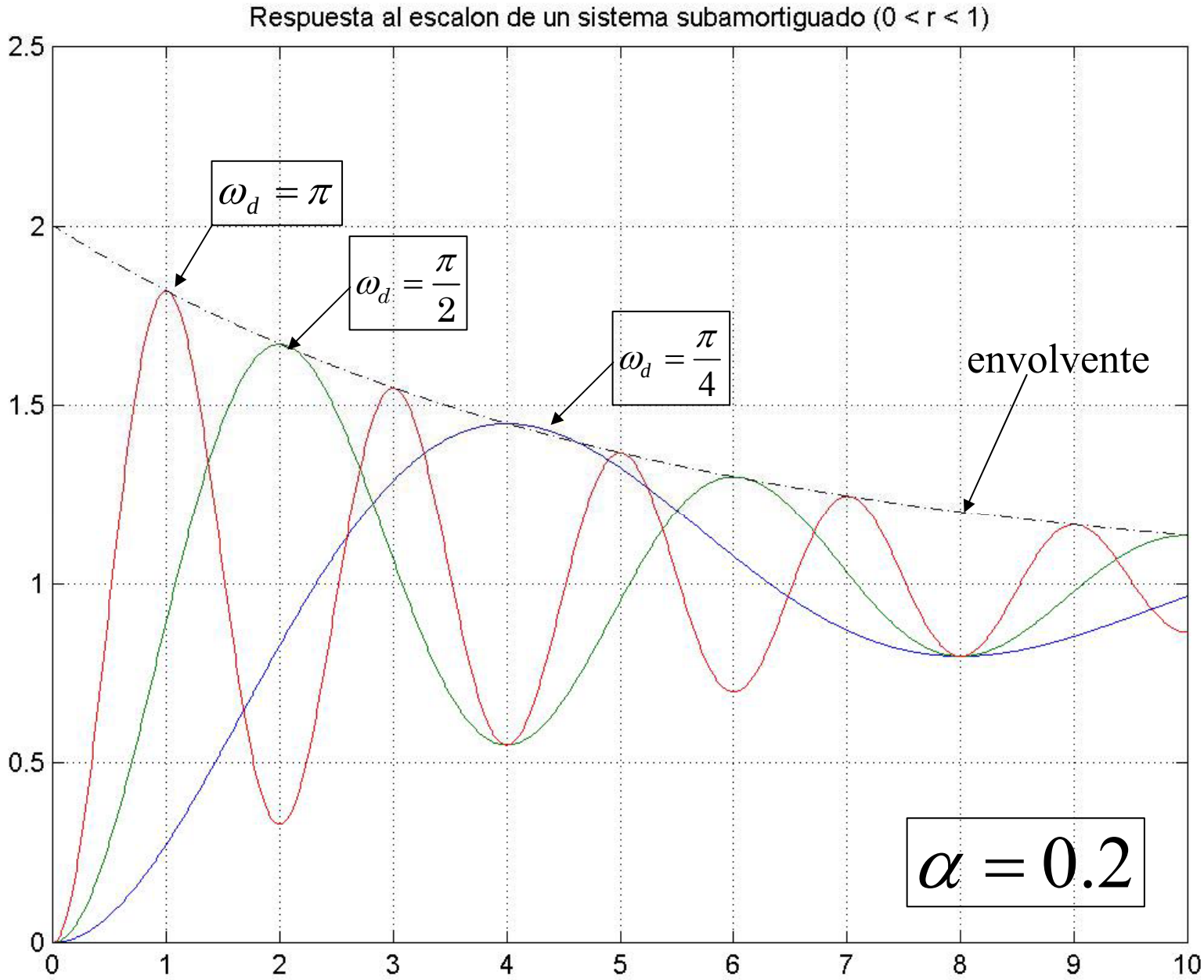


Fuente: Norman S. Nise, Control Systems Engineering, p. 184, Ed. John Wiley & Sons, 2000.

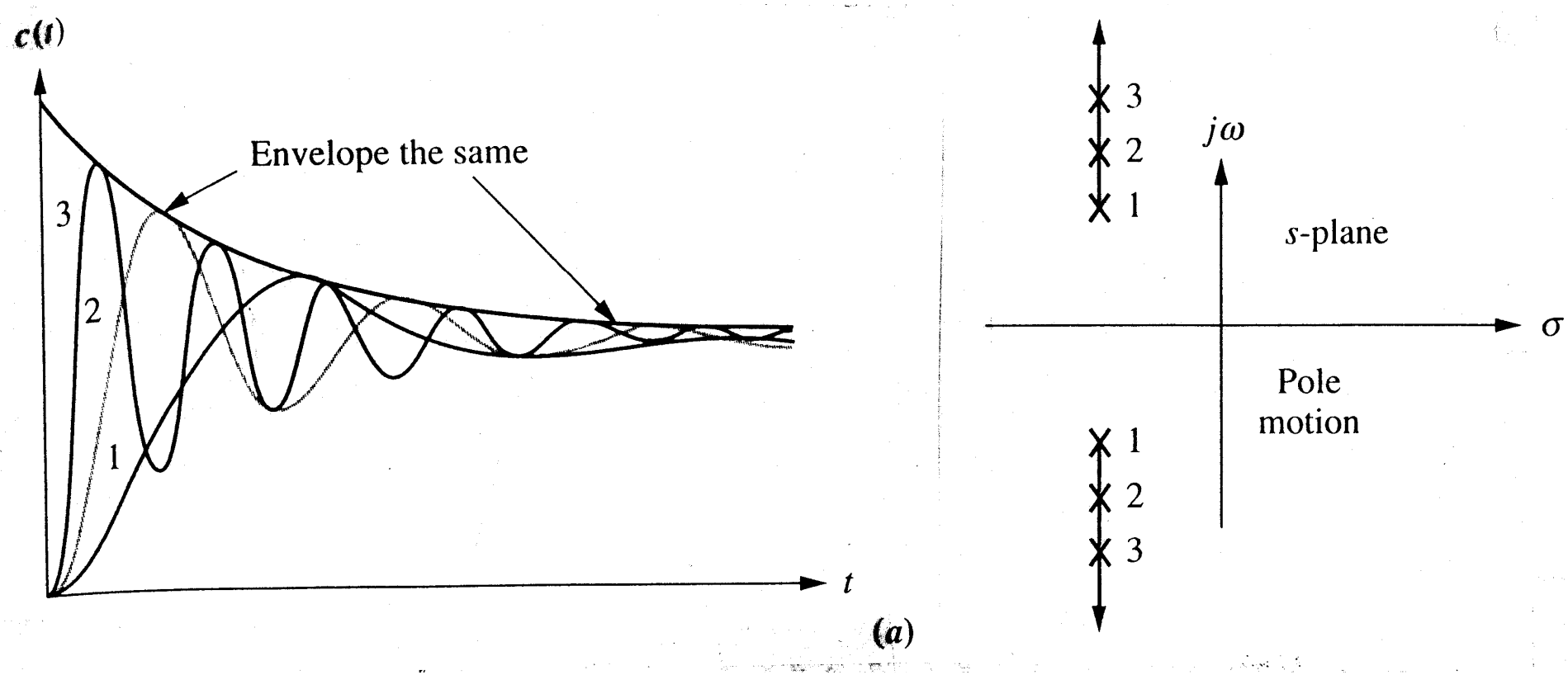
Parámetros de la respuesta al escalón de un sistema de orden 2 subamortiguado



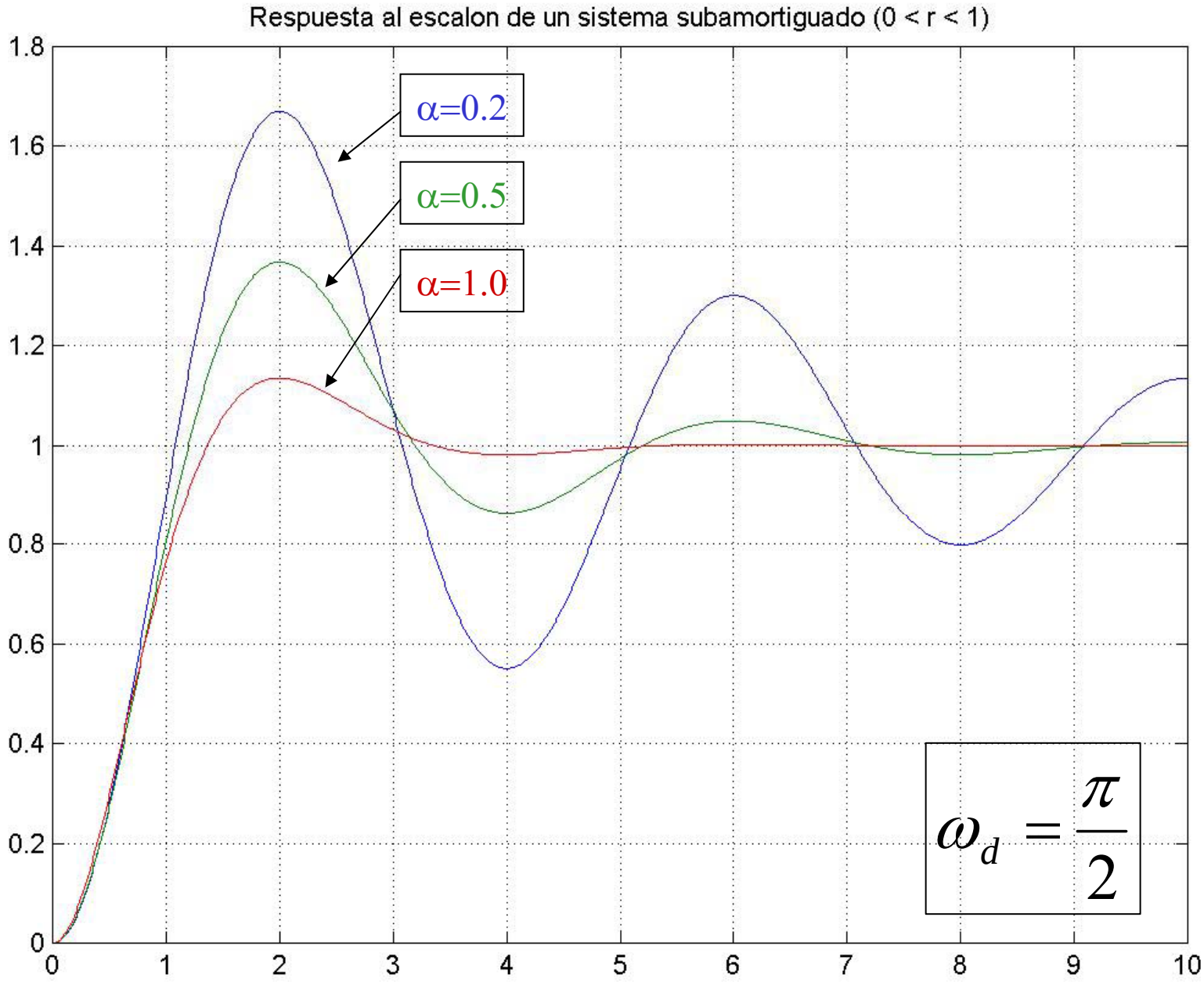
Fuente: Norman S. Nise, Control Systems Engineering, p. 193, Ed. John Wiley & Sons, 2000.


Respuesta al escalon de un sistema subamortiguado (0 < r < 1)
$\omega_d = \pi$
$\omega_d = \frac{\pi}{2}$
$\omega_d = \frac{\pi}{4}$
envolvente
$\alpha = 0.2$
2.5
2
1.5
1
0.5
0
0
1
2
3
4
5
6
7
8
9
10

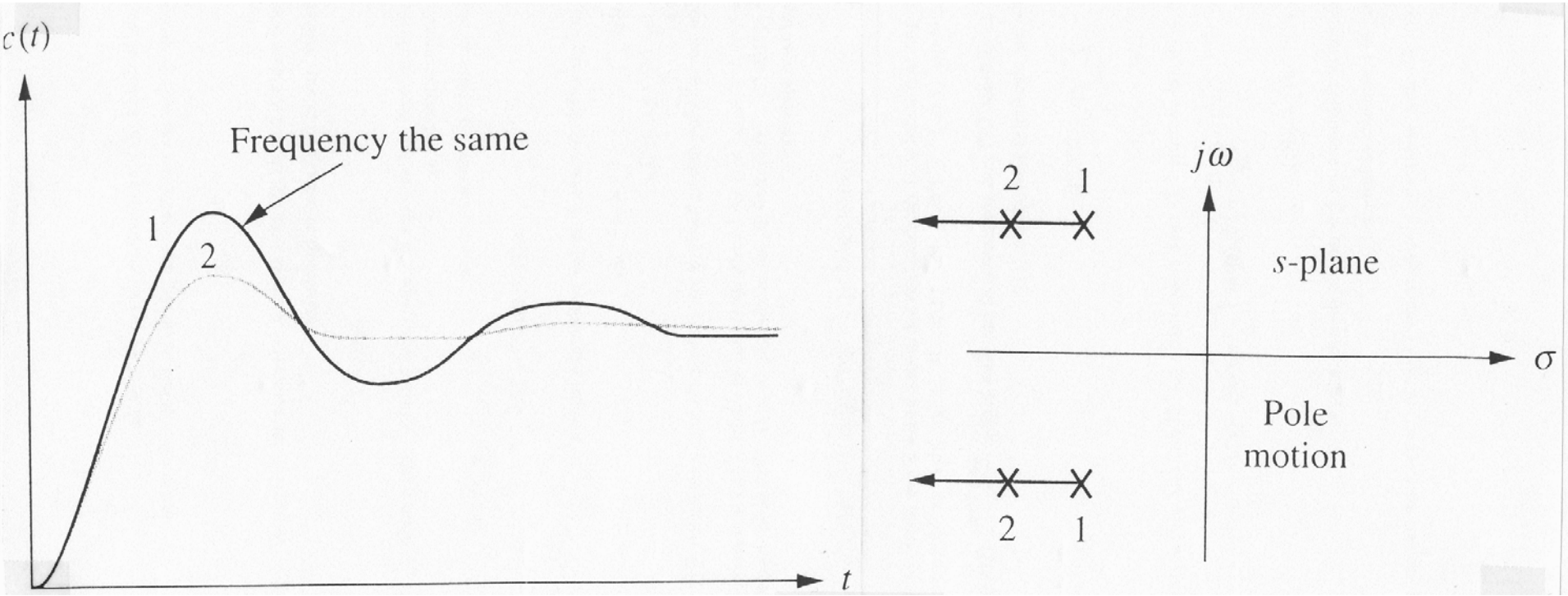
Respuesta al escalón de tres sistemas subamortiguados con la misma constante de amortiguamiento



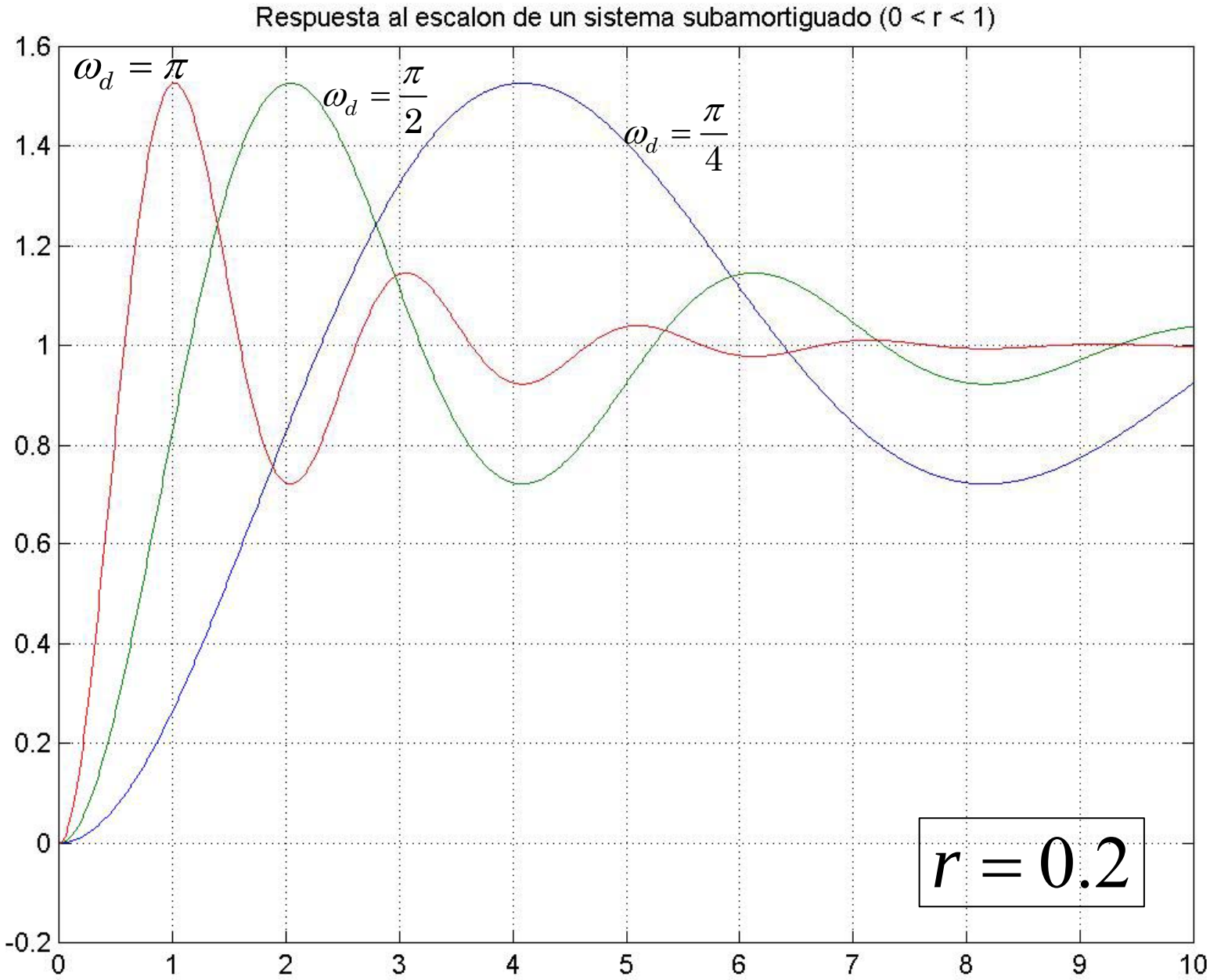
Fuente: Norman S. Nise, Control Systems Engineering, p. 199, Ed. John Wiley & Sons, 2000.


Respuesta al escalon de un sistema subamortiguado (0 < r < 1)
α=0.2
α=0.5
α=1.0
$\omega_d = \frac{\pi}{2}$
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
1
2
3
4
5
6
7
8
9
10

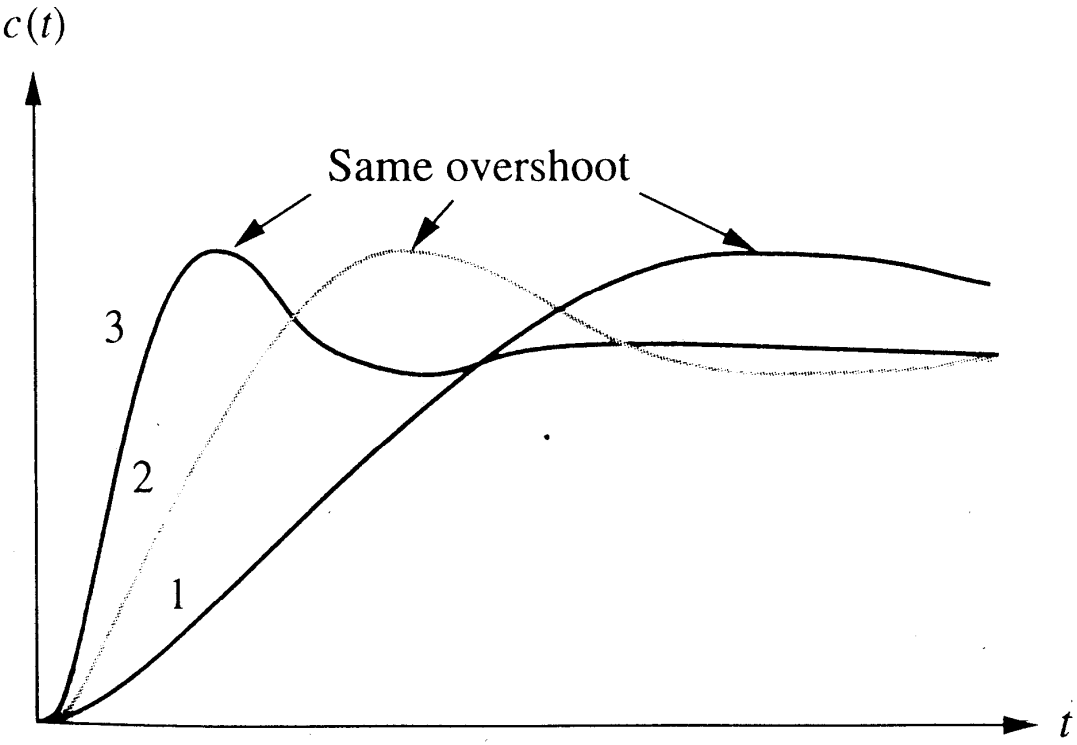
Respuesta al escalón de dos sistemas subamortiguados con la misma frecuencia natural amortiguada

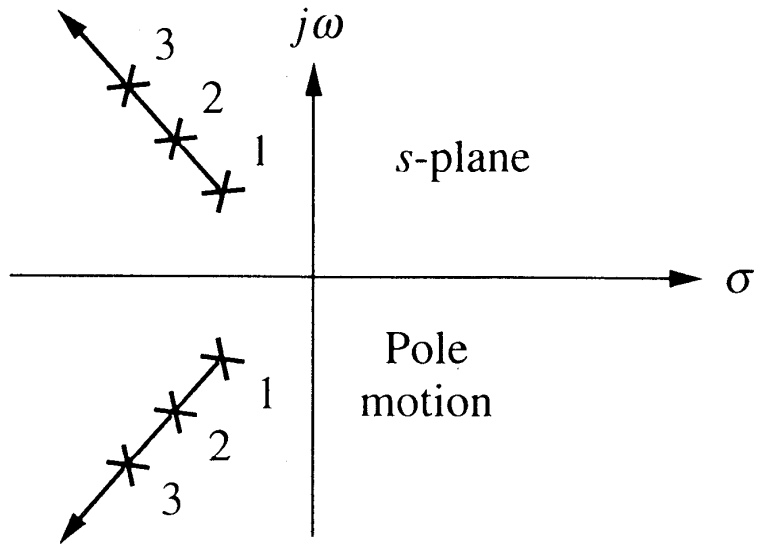


Fuente: Norman S. Nise, Control Systems Engineering, p. 199, Ed. John Wiley & Sons, 2000.

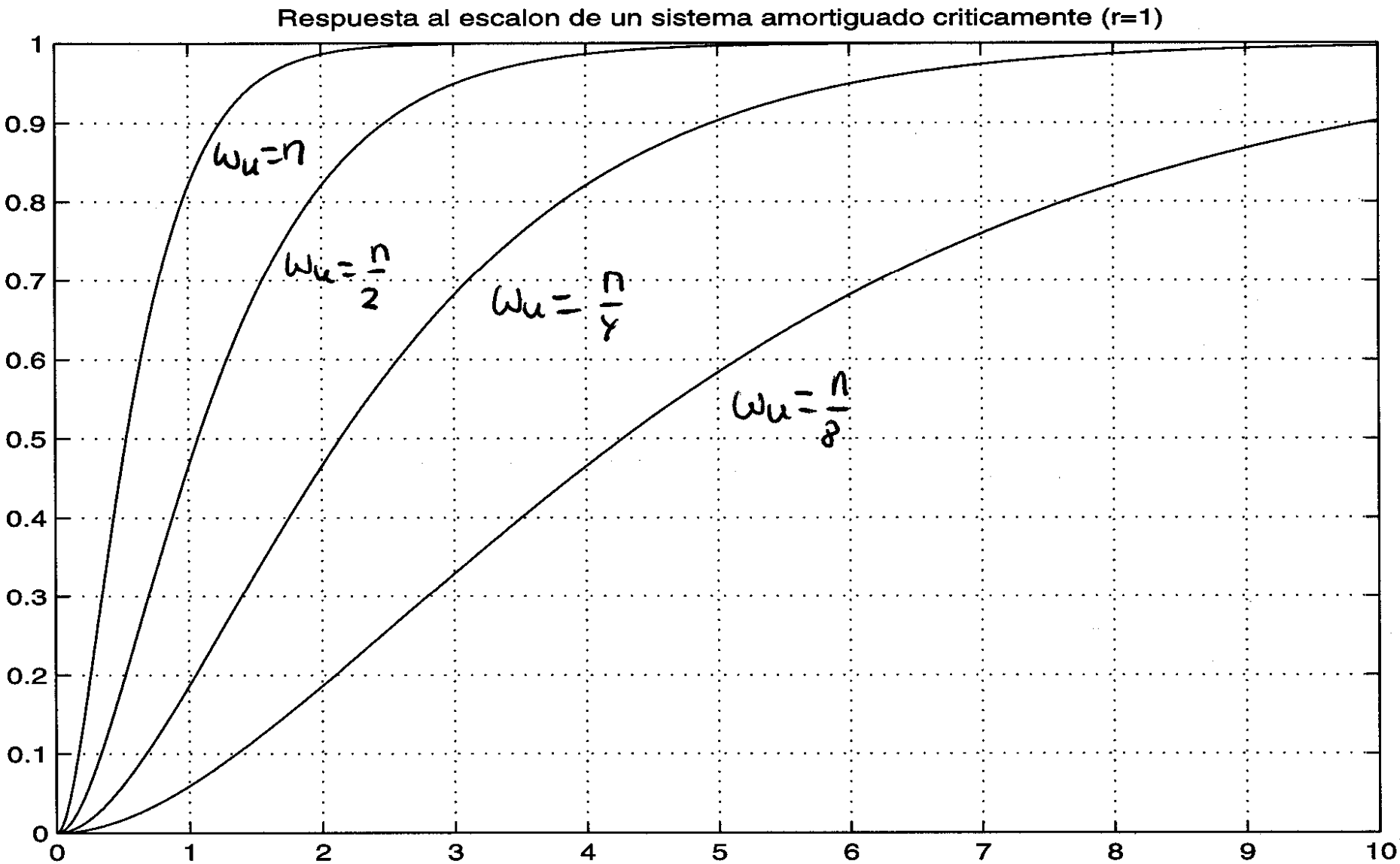

Respuesta al escalon de un sistema subamortiguado (0 < r < 1)
$\omega_d = \pi$
$\omega_d = \frac{\pi}{2}$
$\omega_d = \frac{\pi}{4}$
$r = 0.2$
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
0
1
2
3
4
5
6
7
8
9
10

Respuesta al escalón de tres sistemas subamortiguados con el mismo cociente de amortiguamiento

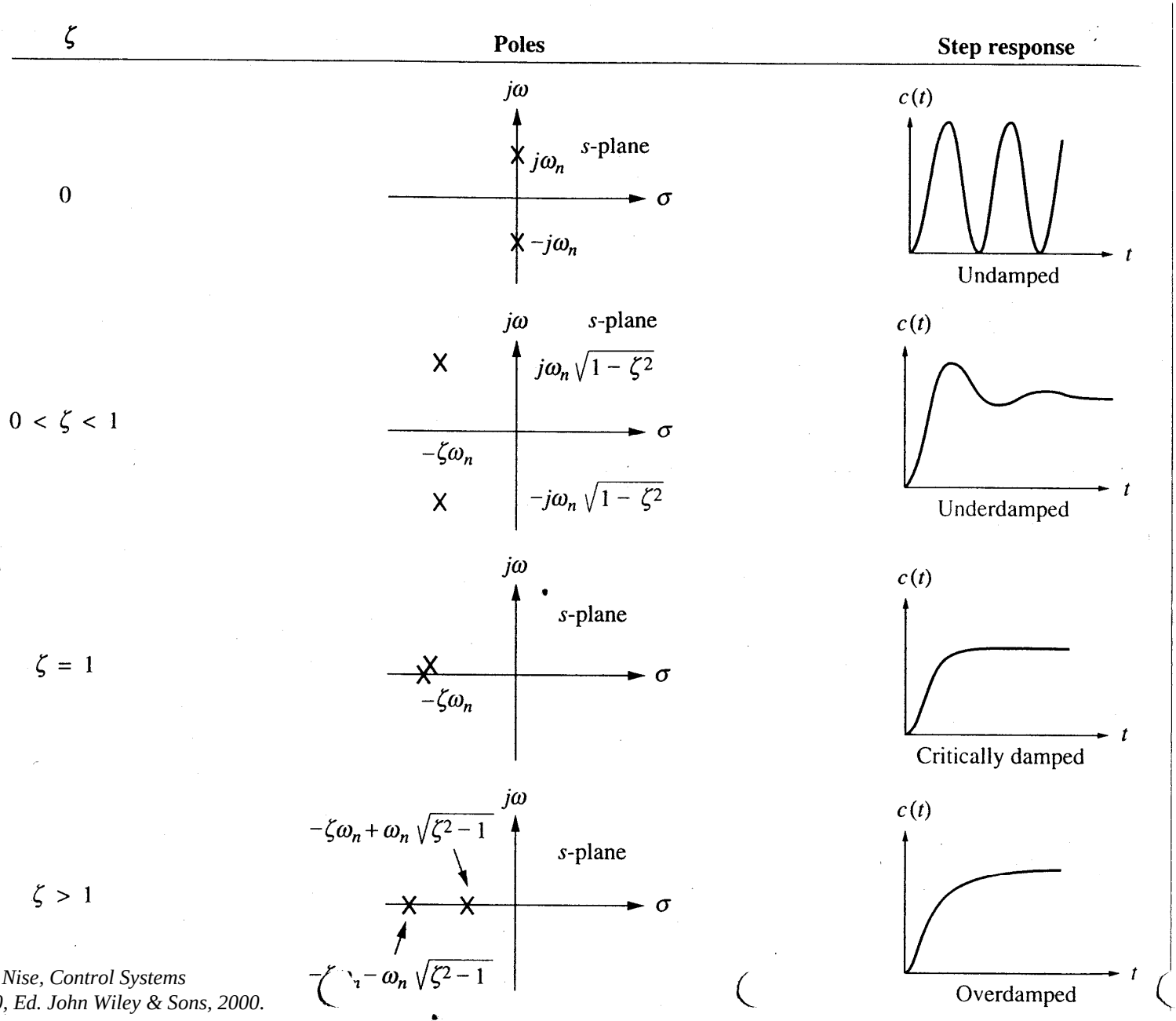




Fuente: Norman S. Nise, Control Systems Engineering, p. 199, Ed. John Wiley & Sons, 2000.


Respuesta al escalon de un sistema amortiguado criticamente (r=1)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1
2
3
4
5
6
7
8
9
10
$\omega_u = n$
$\omega_u = \frac{n}{2}$
$\omega_u = \frac{n}{4}$
$\omega_u = \frac{n}{8}$

Clasificación de los sistemas de orden 2



Fuente: Norman S. Nise, Control Systems Engineering, p. 190, Ed. John Wiley & Sons, 2000.

Respuesta al escalón con error en estado estable

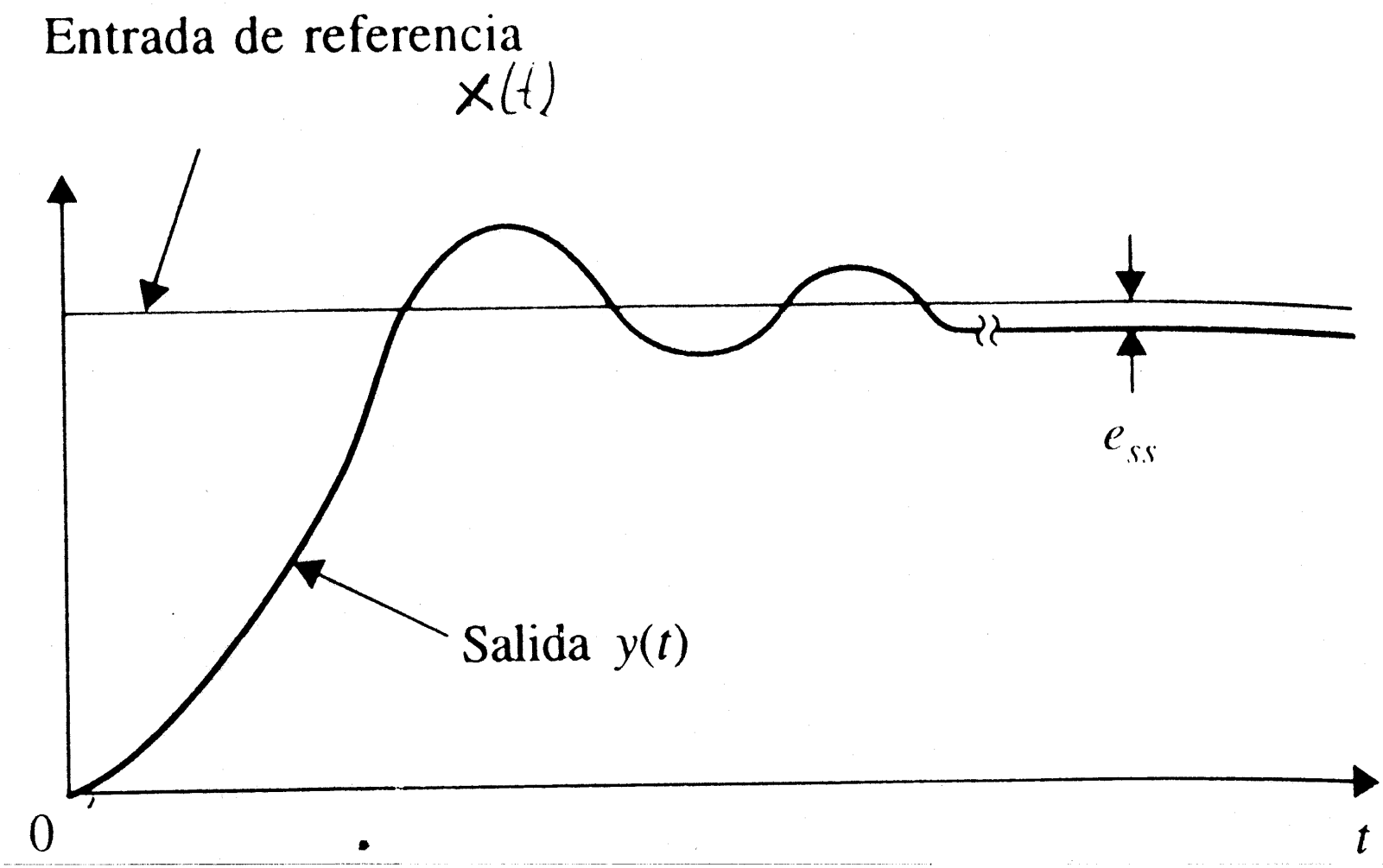
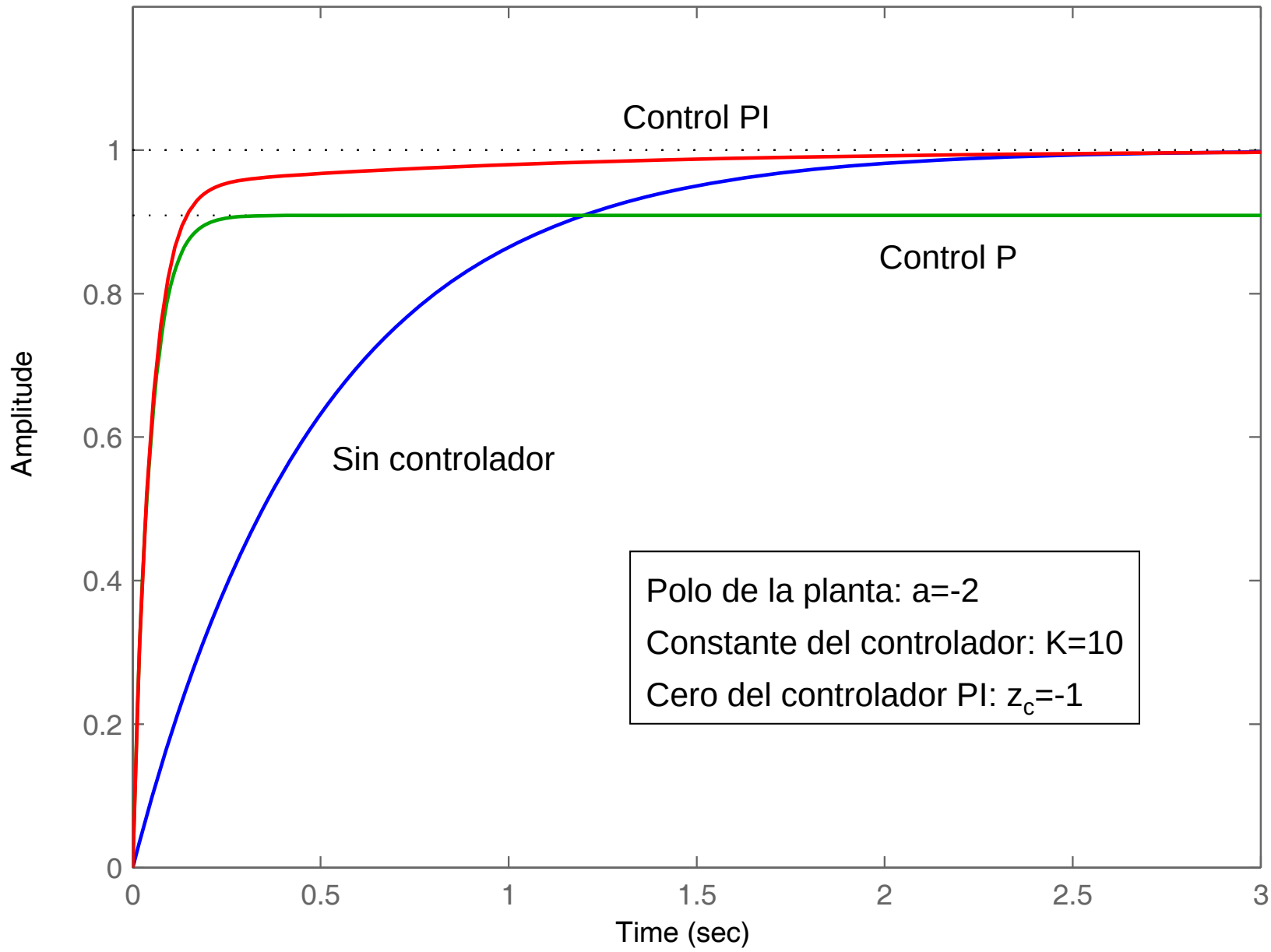


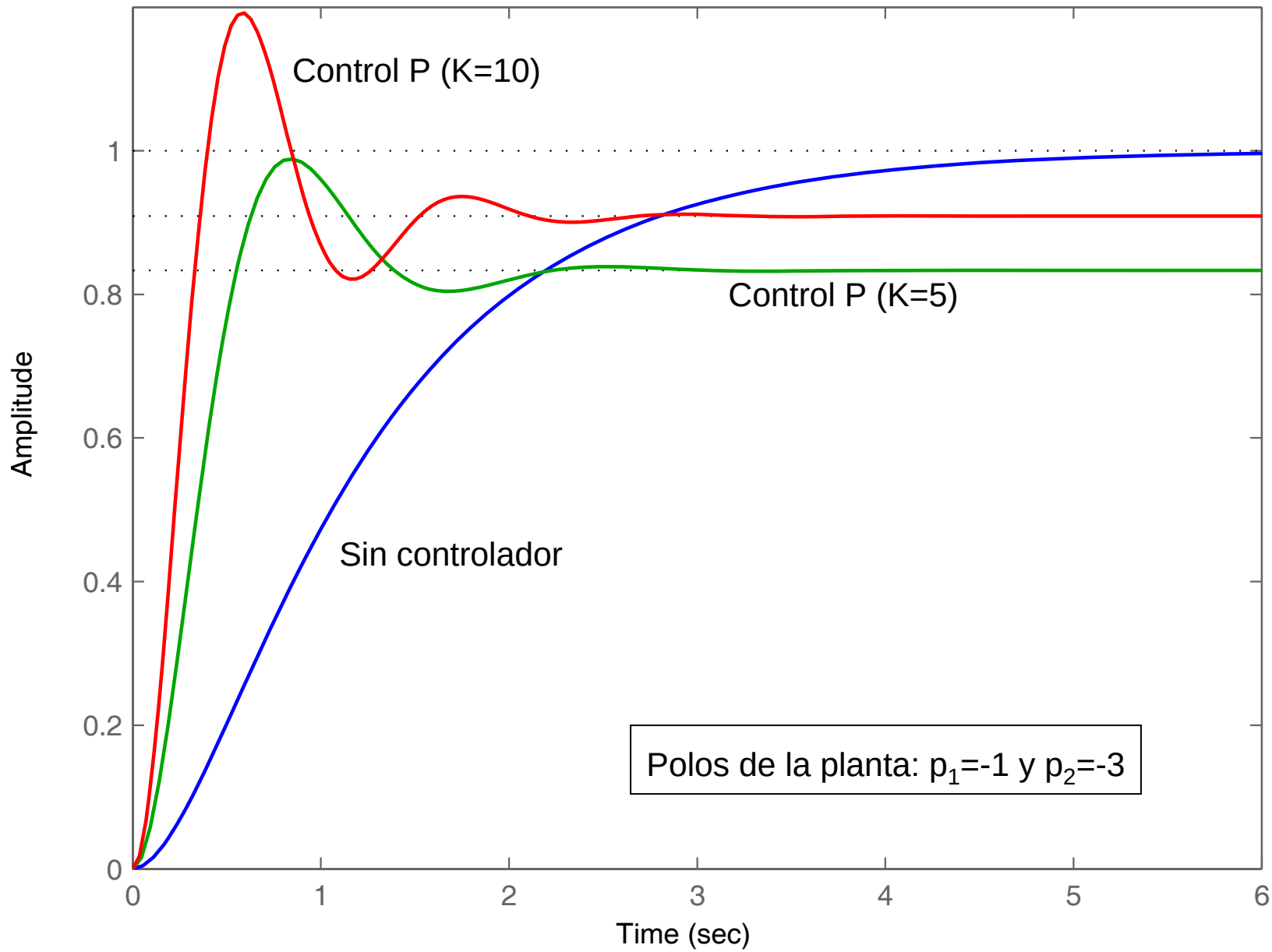
Figura 7-8 Error de estado estable típico, debido a una entrada escalón.

Fuente: Benjamin C. Kuo, Sistemas de Control Automático, p. 372, Ed. Prentice-Hall, 1995.

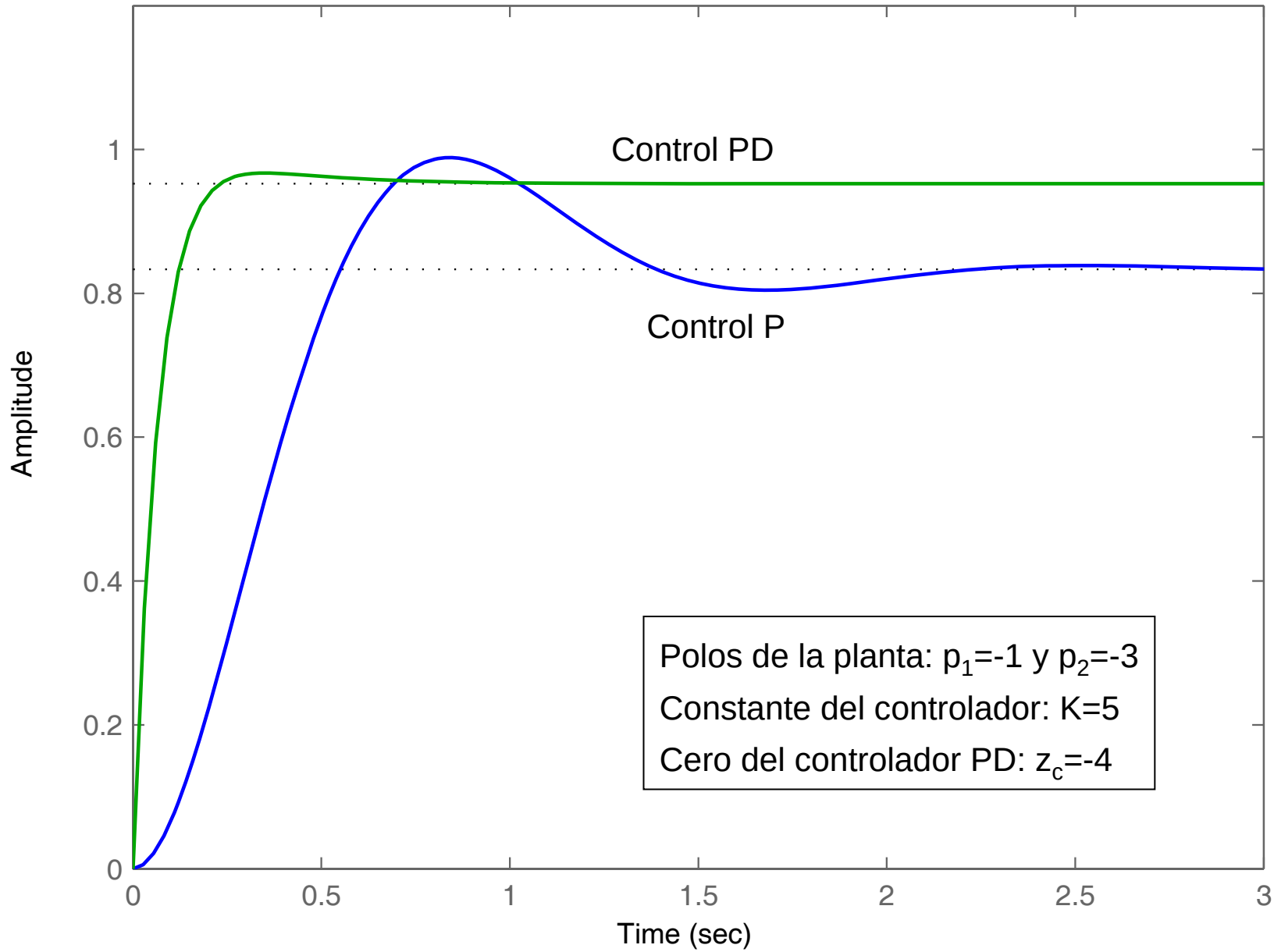
Control de sistemas de orden 1



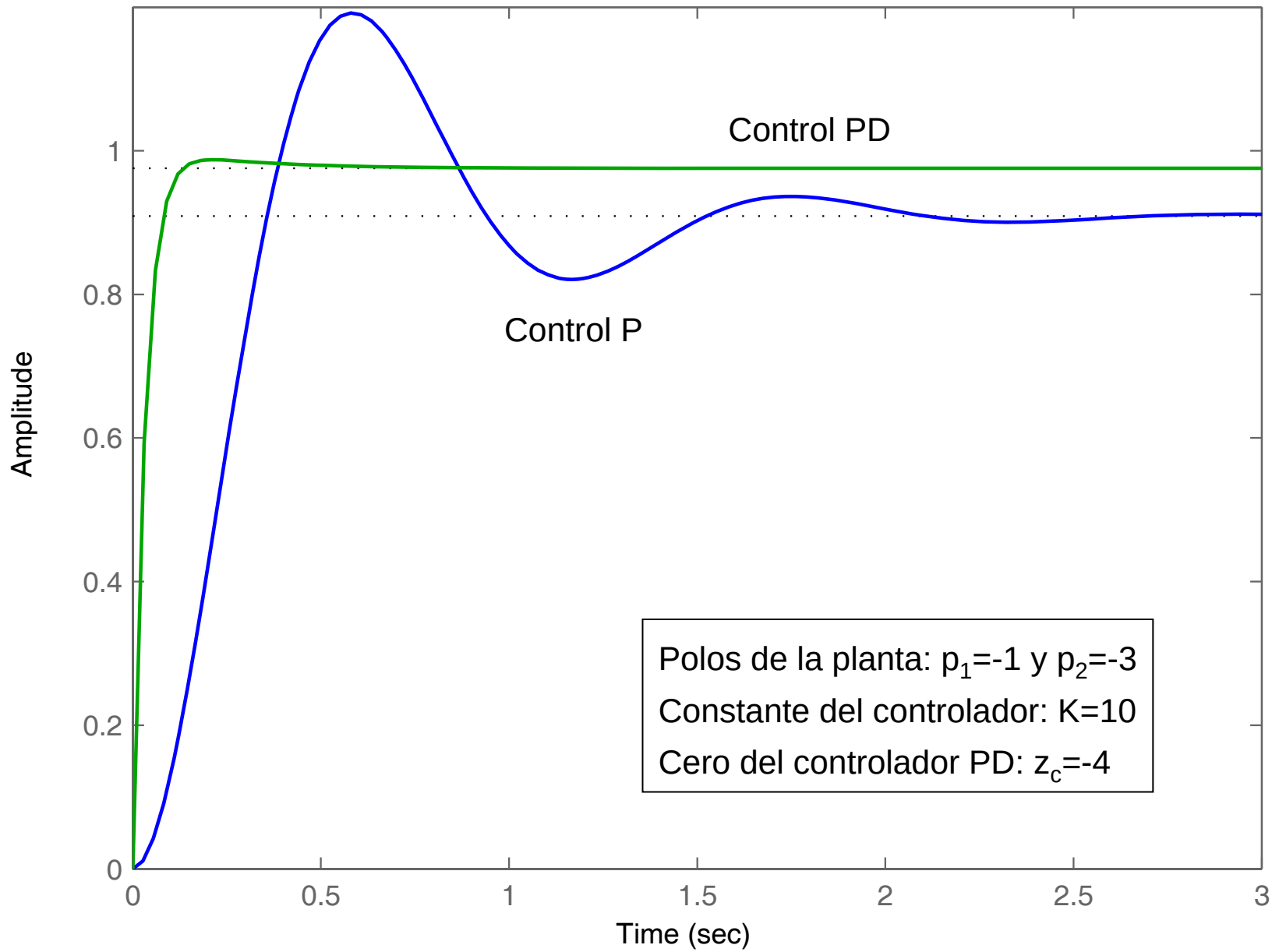
Control P de sistemas de orden 2



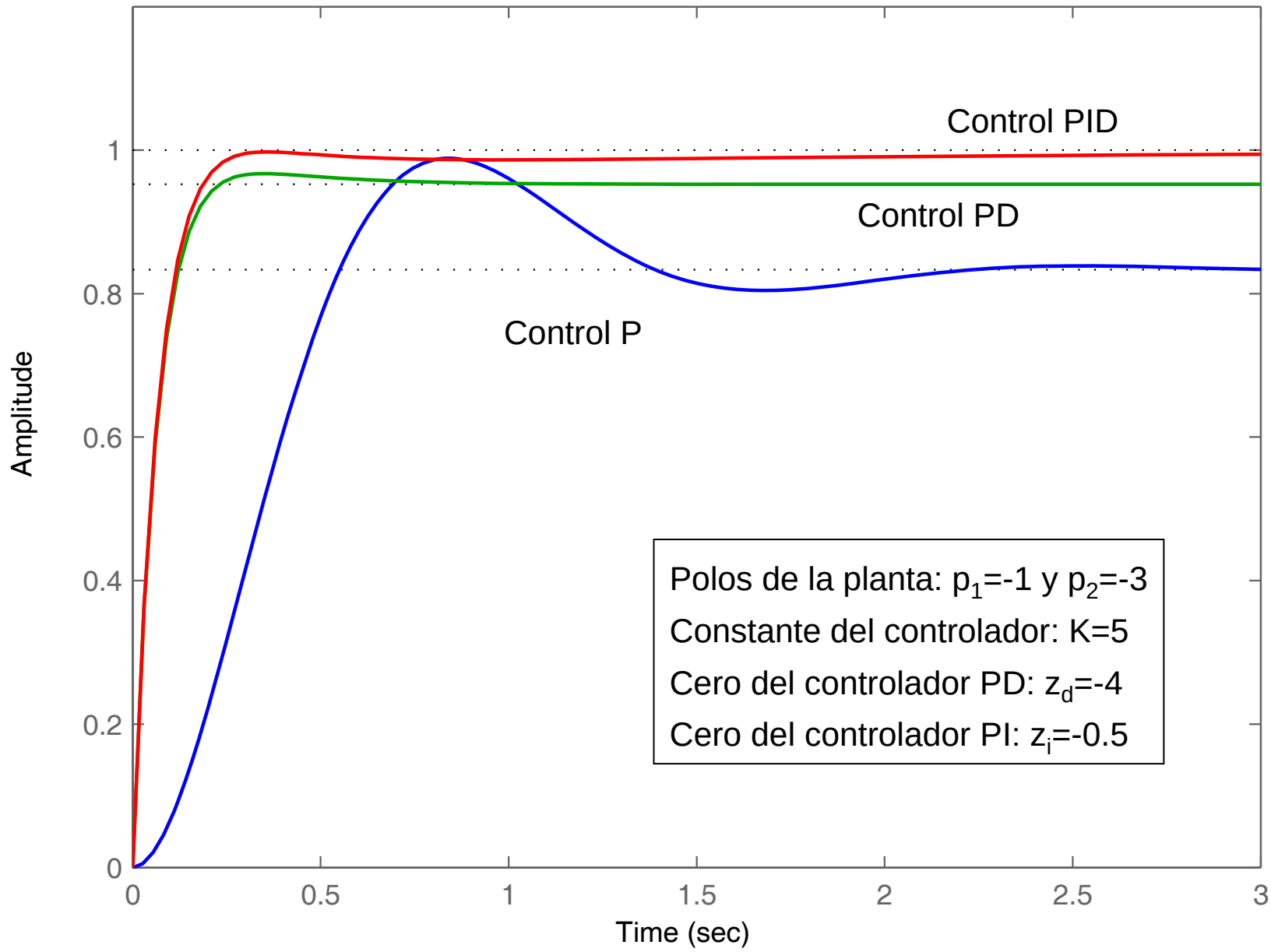
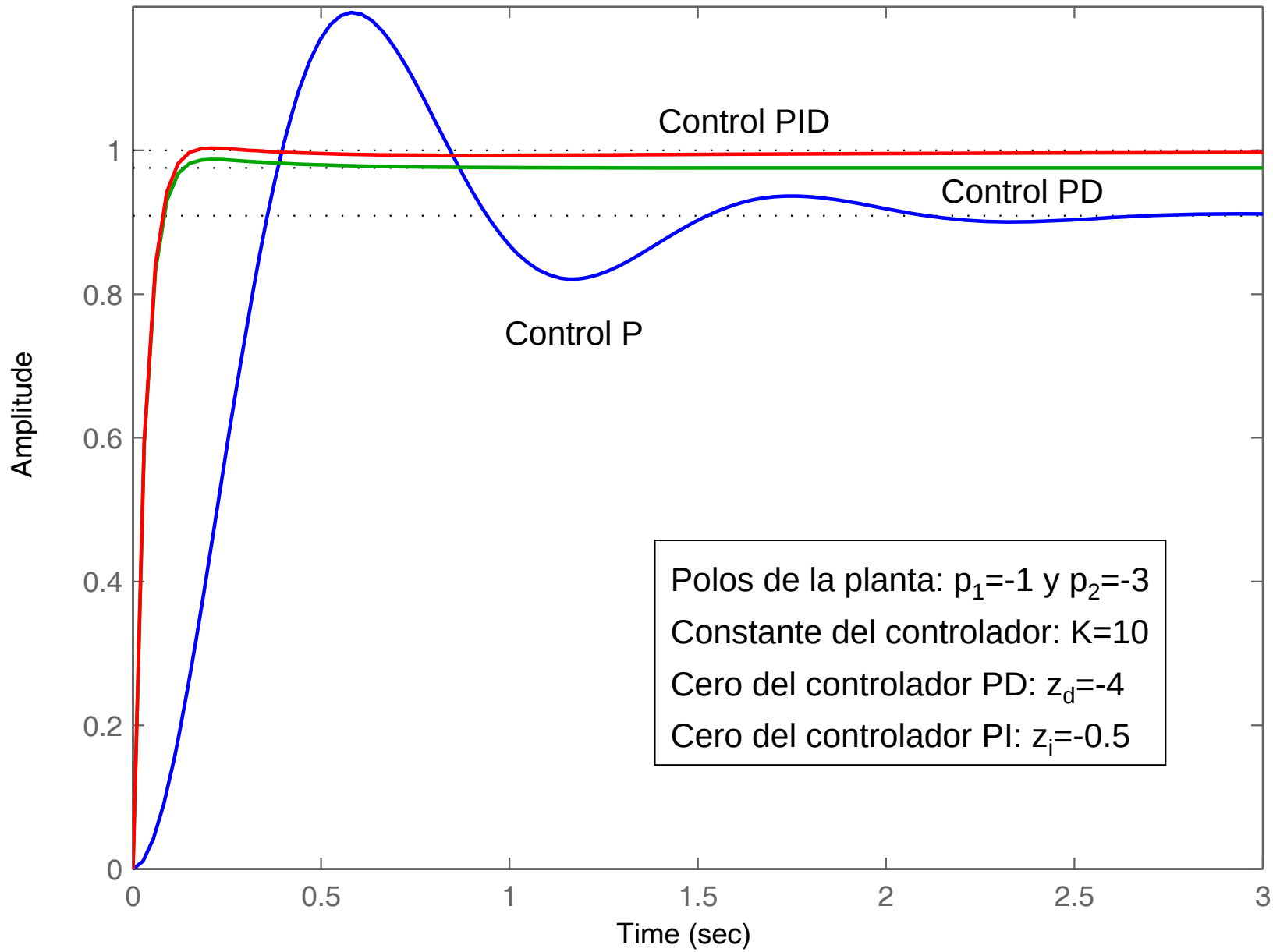
Control PD de sistemas de orden 2 (I)



Control PD de sistemas de orden 2 (II)



Control PID de sistemas de orden 2 (I)



Control PID de sistemas de orden 2 (II)