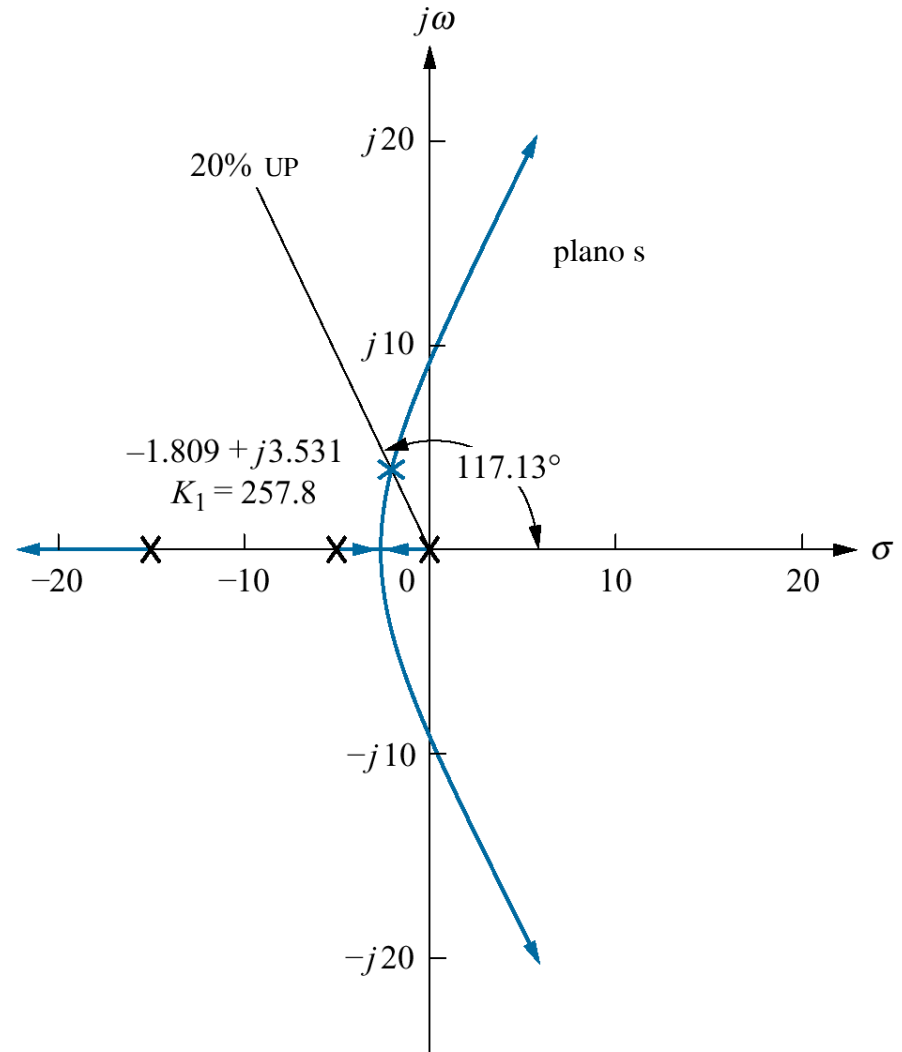


# Capítulo 9

Projeto por Intermédio do  
Lugar das Raízes  
(Continuação)

# Fig. 9.50

Lugar das raízes para o sistema não-compensado do Exemplo 9.7



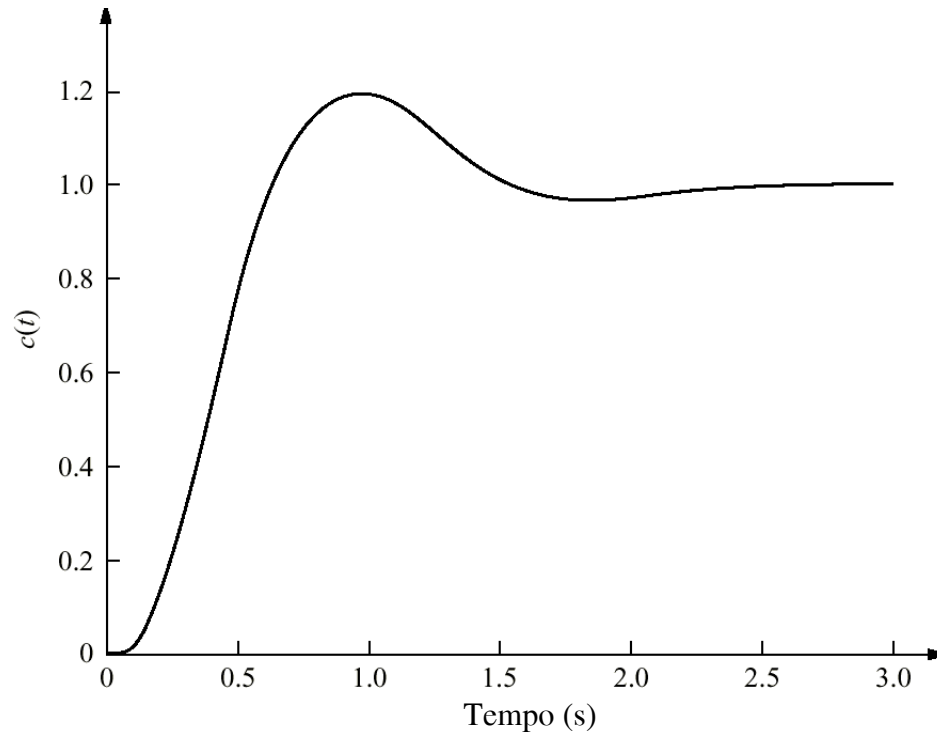
# Tabela 9.8

## Características previstas de sistemas não-compensado e compensado do Exemplo 9.7

Parâmetro	Não-compensado	Compensado
Processo e compensador	$\frac{K_1}{s(s+5)(s+15)}$	$\frac{K_1}{s(s+5)(s+15)}$
Retroação	1	0,85 (s + 5,42))
Pólos dominantes	$-1,809 \pm j 3,531$	$-7,236 \pm j 14,12$
$K_1$	257,8	1388
$\zeta$	0,456	0,456
$\omega_n$	3,97	15,87
%UP	20	20
$T_s$	2,21	0,55
$T_p$	0,89	0,22
$K_v$	3,44	4,18
$e(\infty)$ (rampa)	0,29	0,24
Outros pólos	- 16,4	- 5,53
Zero	Nenhum	Nenhum
Comentários	Aprox. de 2ª-ordem OK	Simular

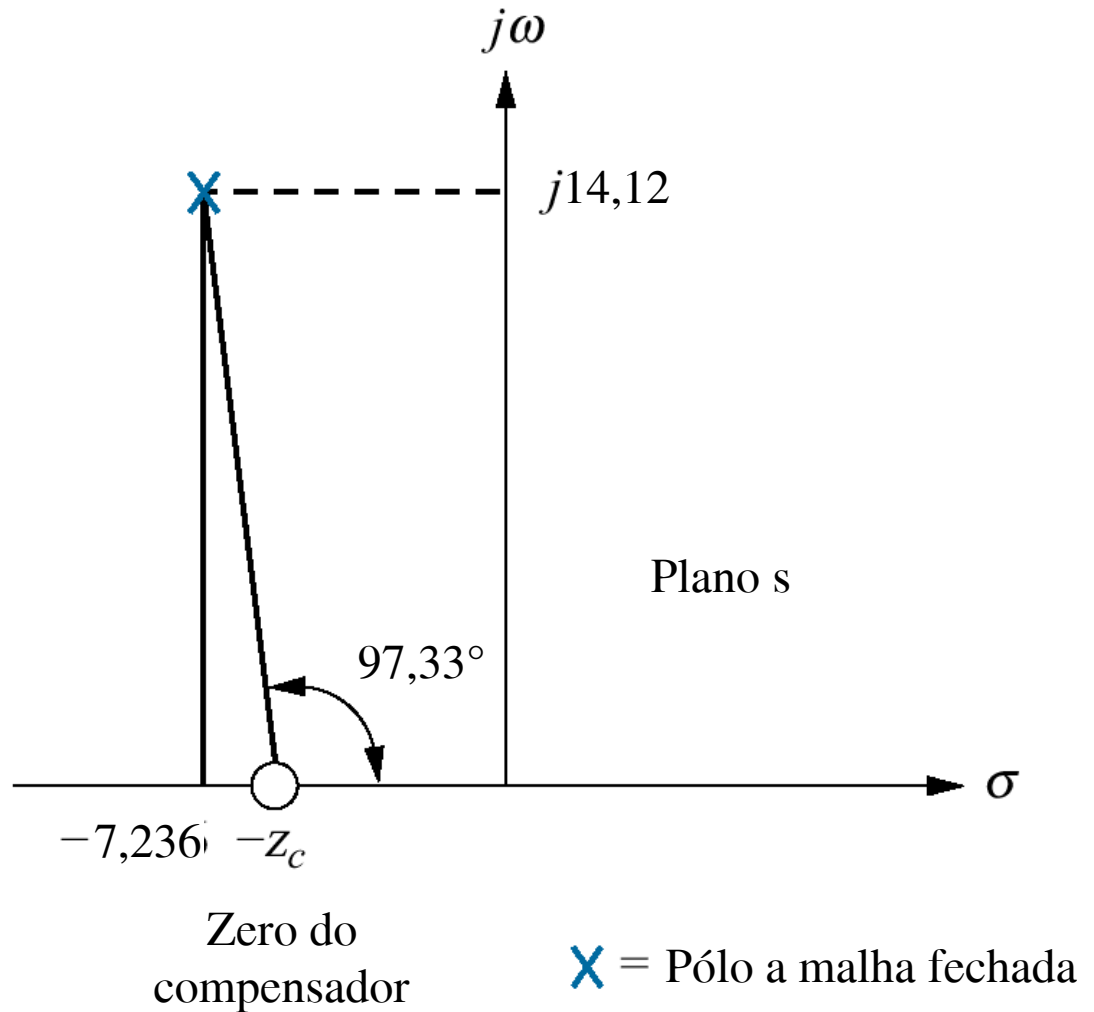
**Fig. 9.51**

Resposta ao degrau para o sistema não-compensado do Exemplo 9.7

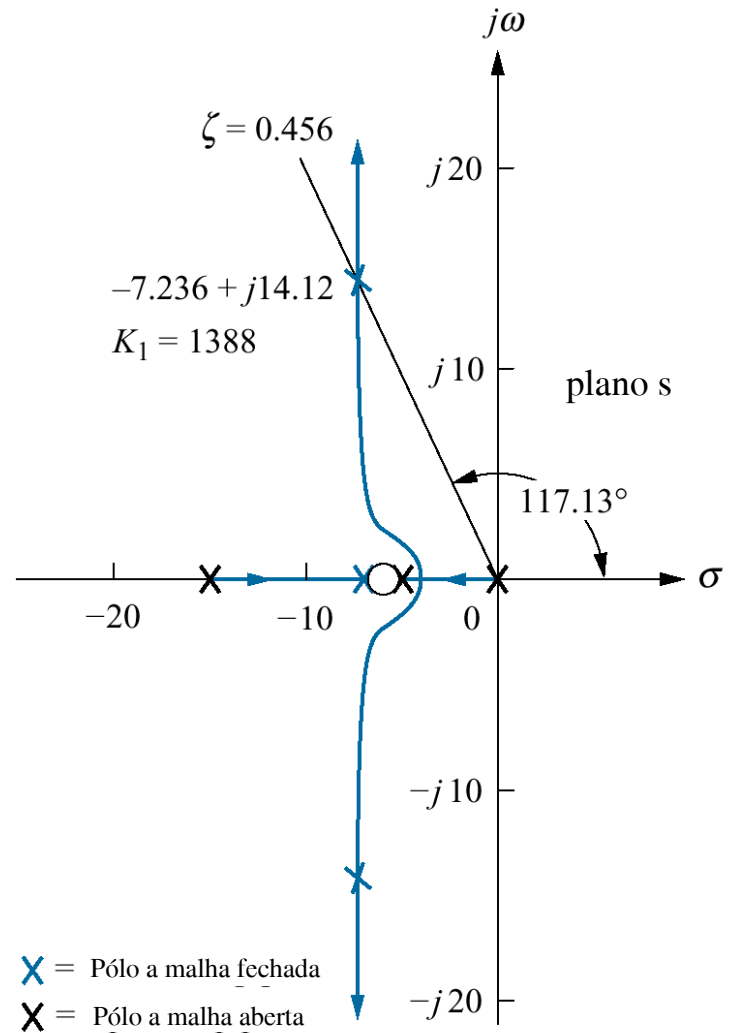


# Fig. 9.52

Determinando o zero do compensador no Exemplo 9.7

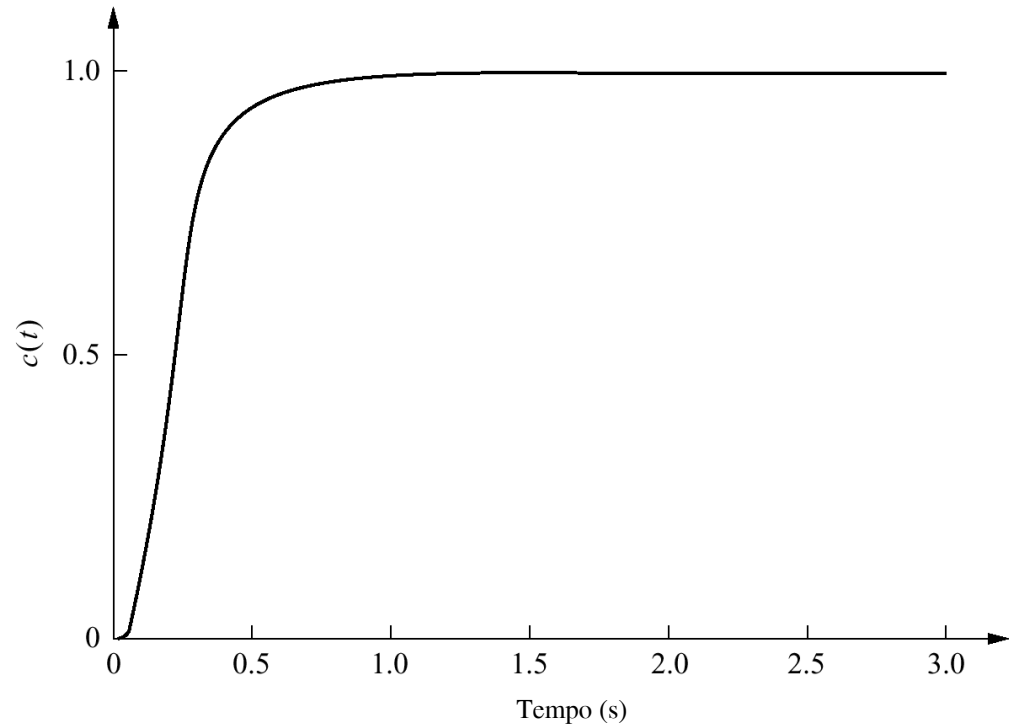


**Fig. 9.53**  
 Lugar das raízes para o sistema compensado do Exemplo 9.7



**Fig. 9.54**

Resposta ao degrau para o sistema compensado do Exemplo 9.7

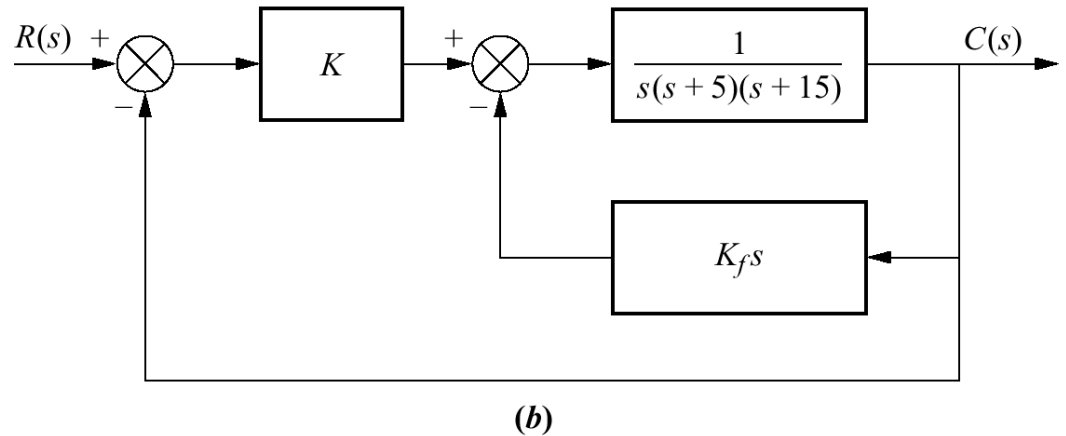
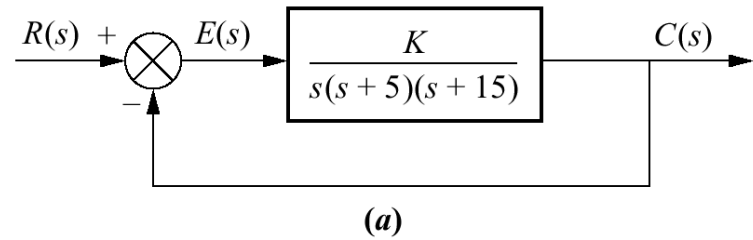


# Fig. 9.55

a. Sistema não-compensado e

b. sistema

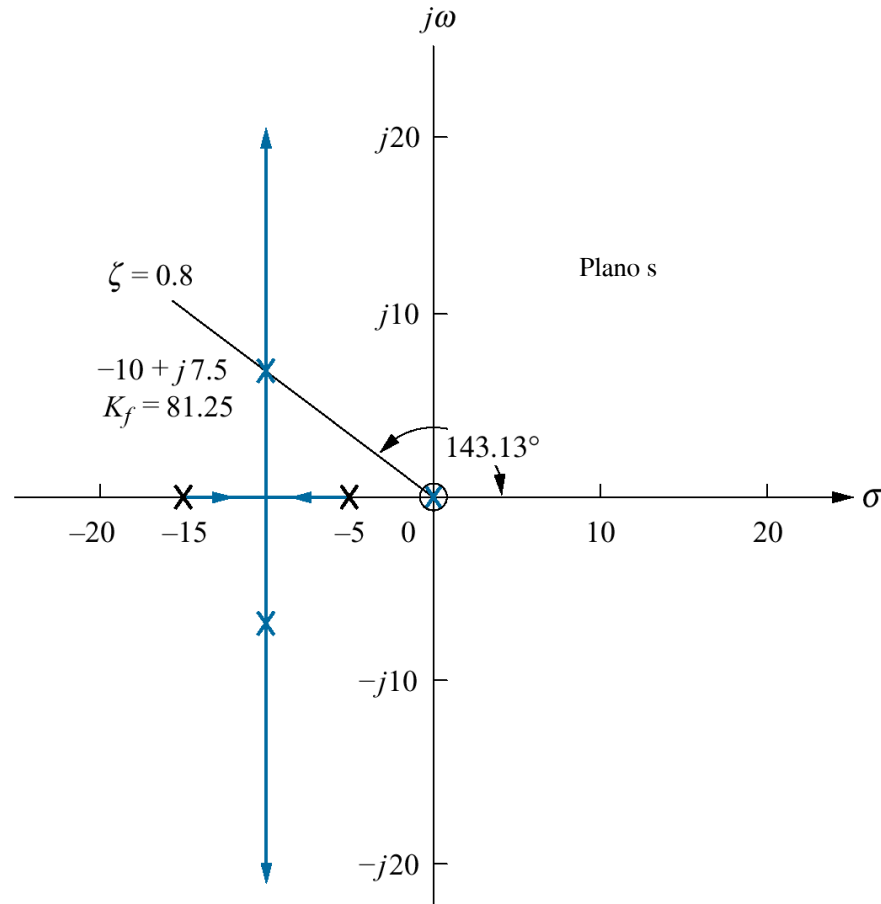
compensado por retroação para o Exemplo 9.8





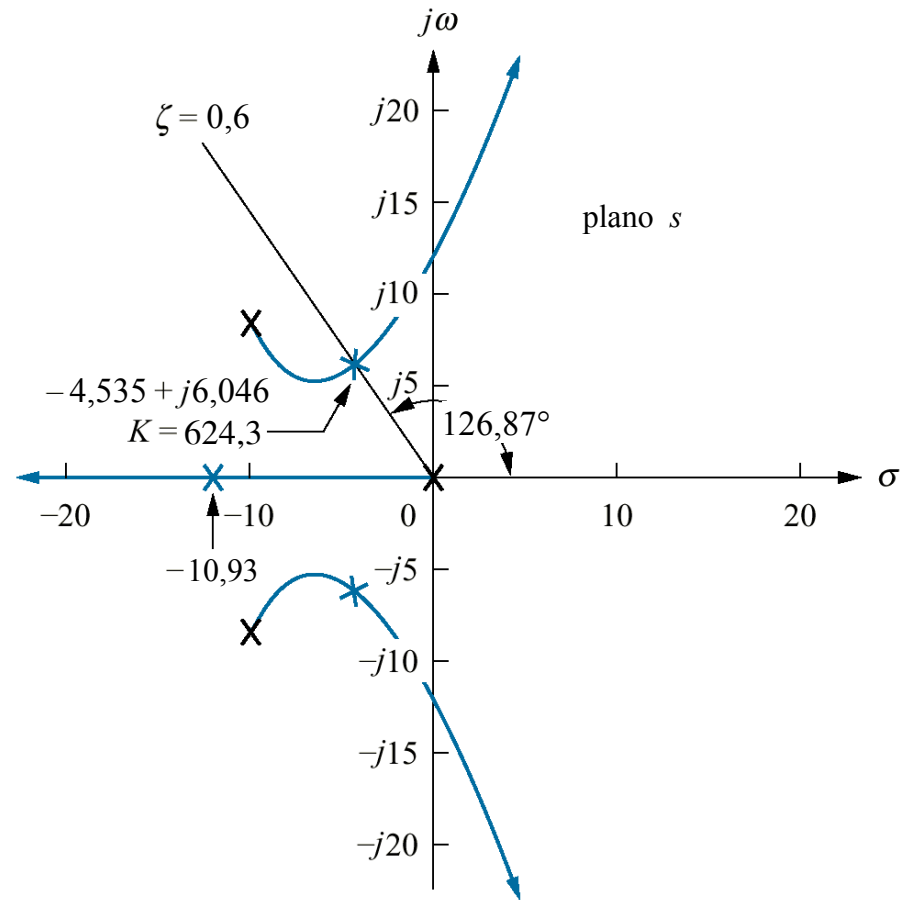
# Fig. 9.56

Lugar das raízes para a malha secundária do Exemplo 9.8



$\times$  = Pólo a malha fechada (malha secundária)  
 $\times$  = Pólo a malha aberta

**Fig. 9.57**  
 Lugar das raízes para o sistema a malha fechada do Exemplo 9.8



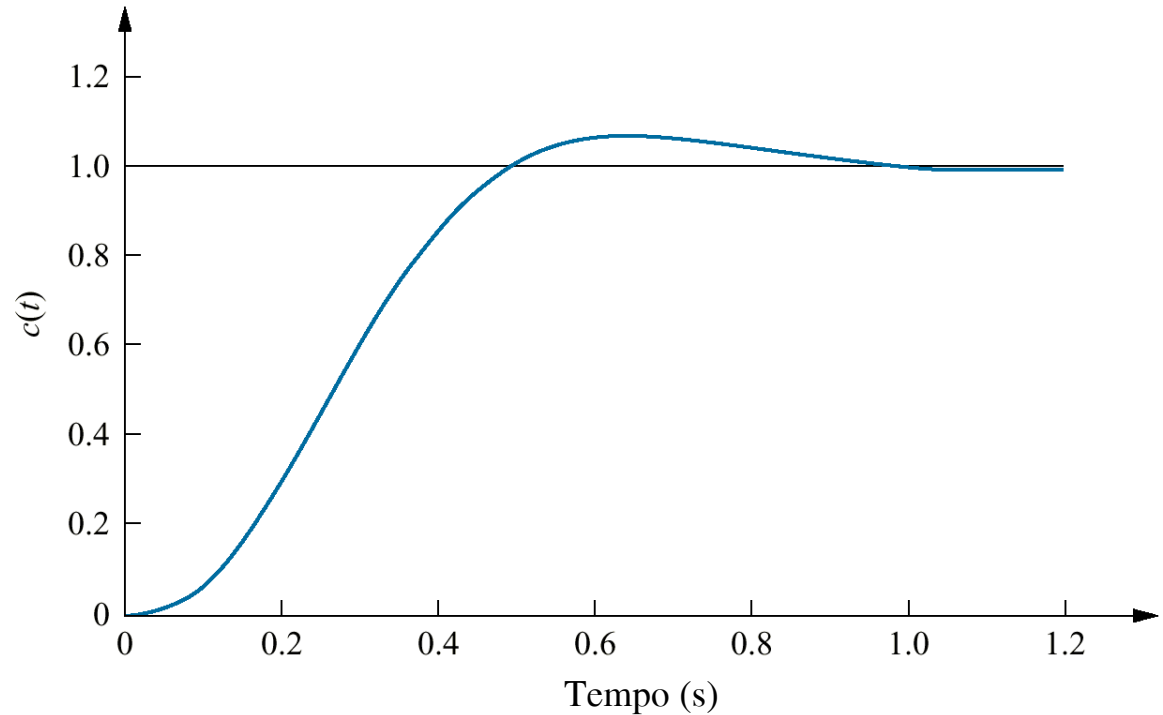
**x** = Pólo a malha fechada  
**X** = Pólo a malha aberta

# Tabela 9.9

## Características previstas de sistemas não-compensado e compensado do Exemplo 9.8

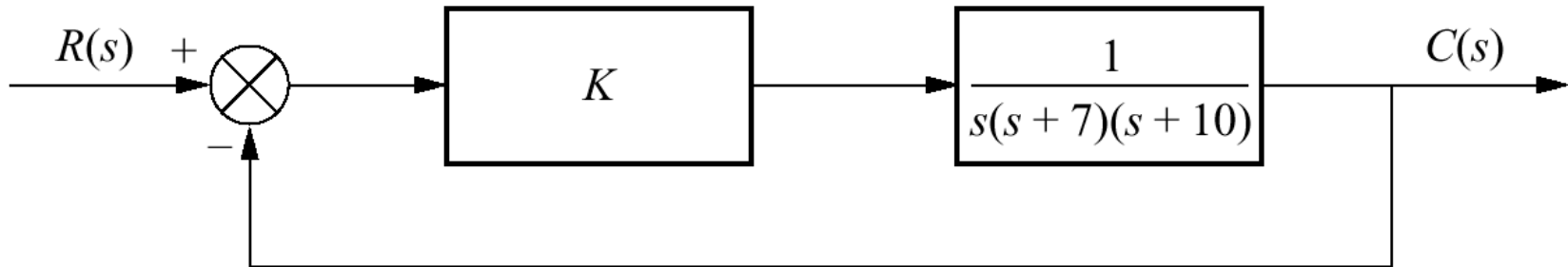
Parâmetro	Não-compensado	Compensado
Processo e compensador	$\frac{K}{s(s+5)(s+15)}$	$\frac{K}{s(s^2+20s+156,25)}$
Retroação	1	1
Pólos dominantes	$-1,997 \pm j 2,662$	$-4,535 \pm j 6,046$
$K$	177,3	624,3
$\zeta$	0,6	0,6
$\omega_n$	3,328	7,558
%UP	9,48	9,48
$T_s$	2	0,882
$T_p$	1,18	0,52
$K_v$	2,364	3,996
$e(\infty)$ (rampa)	0,423	0,25
Outros pólos	-16	-10,93
Zero	Nenhum	Nenhum
Comentários	Aprox. de 2ª ordem, OK	Simular

**Fig. 9.58**  
Simulação da  
resposta ao  
degrau para o  
Exemplo 9.8



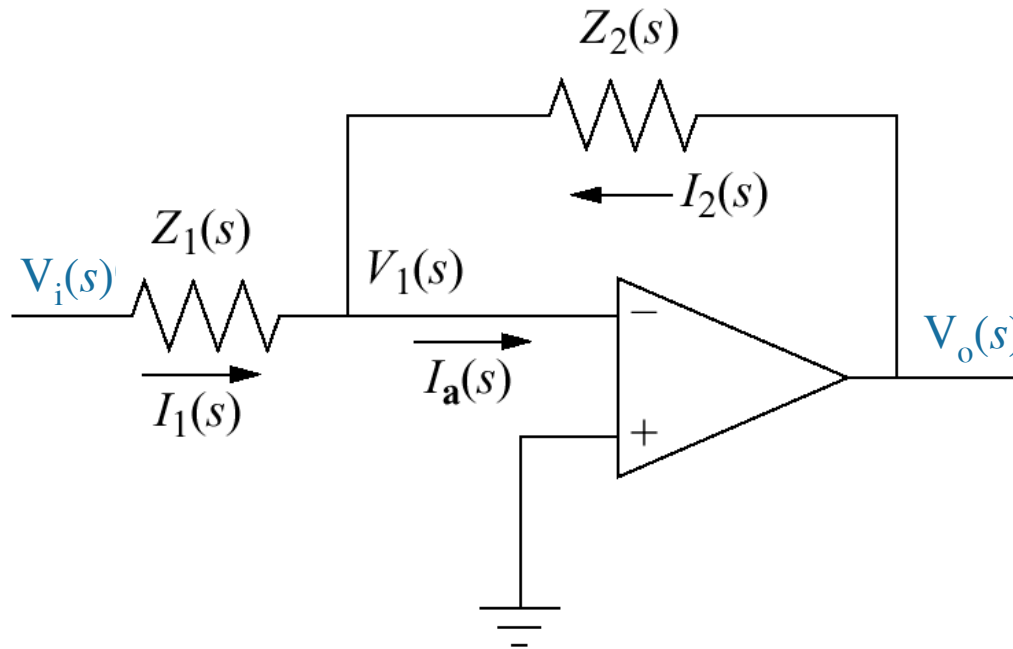
**Fig. 9.59**

Sistema para o Exercício  
de Avaliação 9.4



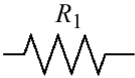
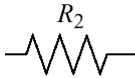
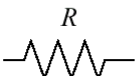



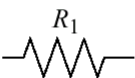
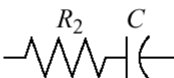
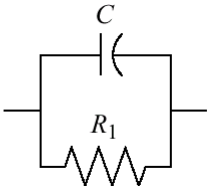
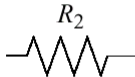
## Fig. 9.60

Amplificador operacional configurado para realização de função de transferência



# Tabela 9.10

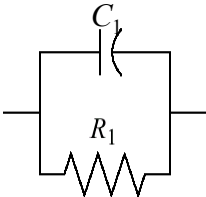
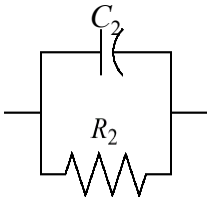
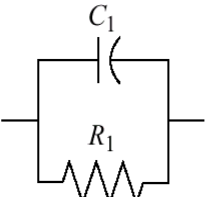
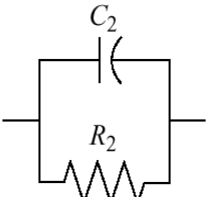
## Realização ativa de controladores e de compensadores, usando um amplificador operacional (slide 1 de 2)

Função	$Z_1(s)$	$Z_2(s)$	$G_c(s) = -\frac{Z_2(s)}{Z_1(s)}$
Ganho			$-\frac{R_2}{R_1}$
Integração			$-\frac{1}{RCs}$
Derivação			$-RCs$
Controlador PI			$-\frac{R_2}{R_1} \left( s + \frac{1}{R_2 C} \right)$
Controlador PD			$-R_2 C \left( s + \frac{1}{R_1 C} \right)$

(continua no próximo slide)

# Tabela 9.10

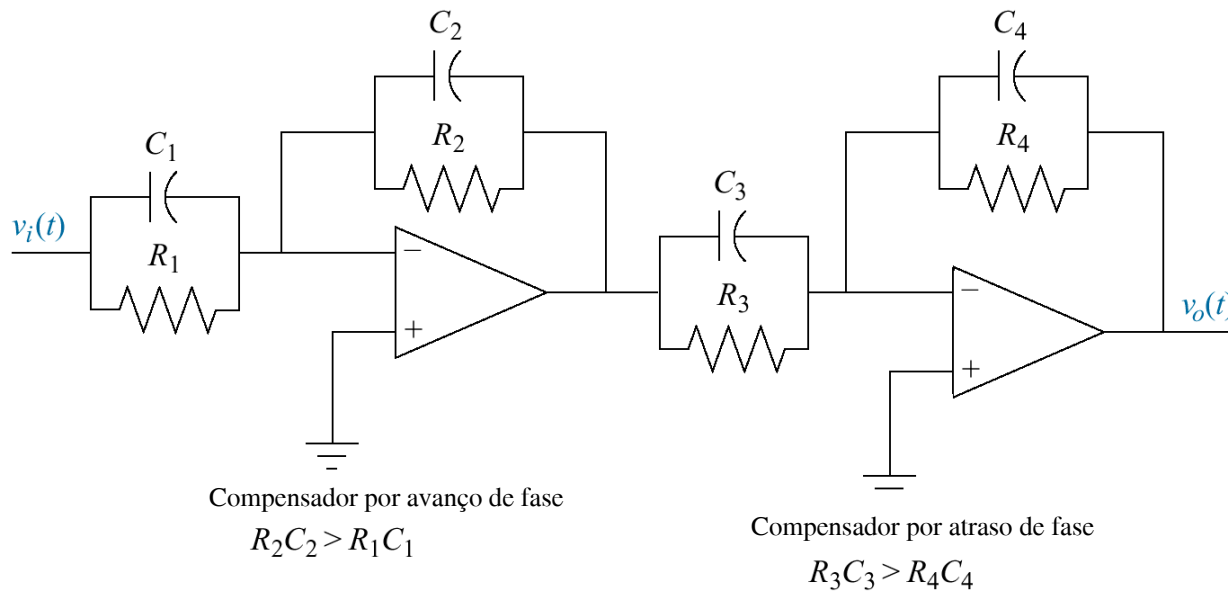
Realização ativa de controladores e de compensadores, usando um amplificador operacional (slide 2 de 2)

Função	$Z_1(s)$	$Z_2(s)$	$G_c(s) = -\frac{Z_2(s)}{Z_1(s)}$
Compensação por atraso de fase			$-\frac{C_1 \left( s + \frac{1}{R_1 C_1} \right)}{C_2 \left( s + \frac{1}{R_2 C_2} \right)}$ <p>onde <math>R_2 C_2 &gt; R_1 C_1</math></p>
Compensação por avanço de fase			$-\frac{C_1 \left( s + \frac{1}{R_1 C_1} \right)}{C_2 \left( s + \frac{1}{R_2 C_2} \right)}$ <p>onde : <math>R_1 C_1 &gt; R_2 C_2</math></p>

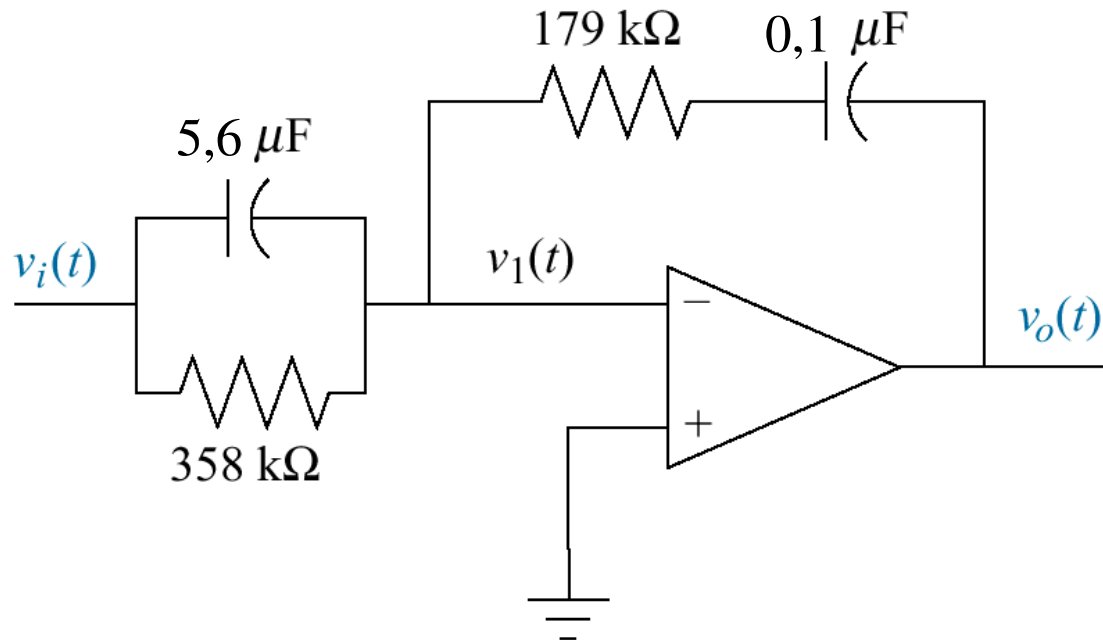


# Fig. 9.61

Compensador por atraso e avanço de fase implementado com amplificadores operacionais



**Fig. 9.62**  
Controlador PID



# Tabela 9.11

## Realização passiva de compensadores (slide 1 de 2)

Função	Circuito	Função de transferência $\frac{V_o(s)}{V_i(s)}$
Compensação por atraso de fase		$\frac{R_2}{R_1 + R_2} \frac{s + \frac{1}{R_2 C}}{s + \frac{1}{(R_1 + R_2) C}}$
Compensação por avanço de fase		$\frac{s + \frac{1}{R_1 C}}{s + \frac{1}{R_1 C} + \frac{1}{R_2 C}}$

(continua no próximo slide)

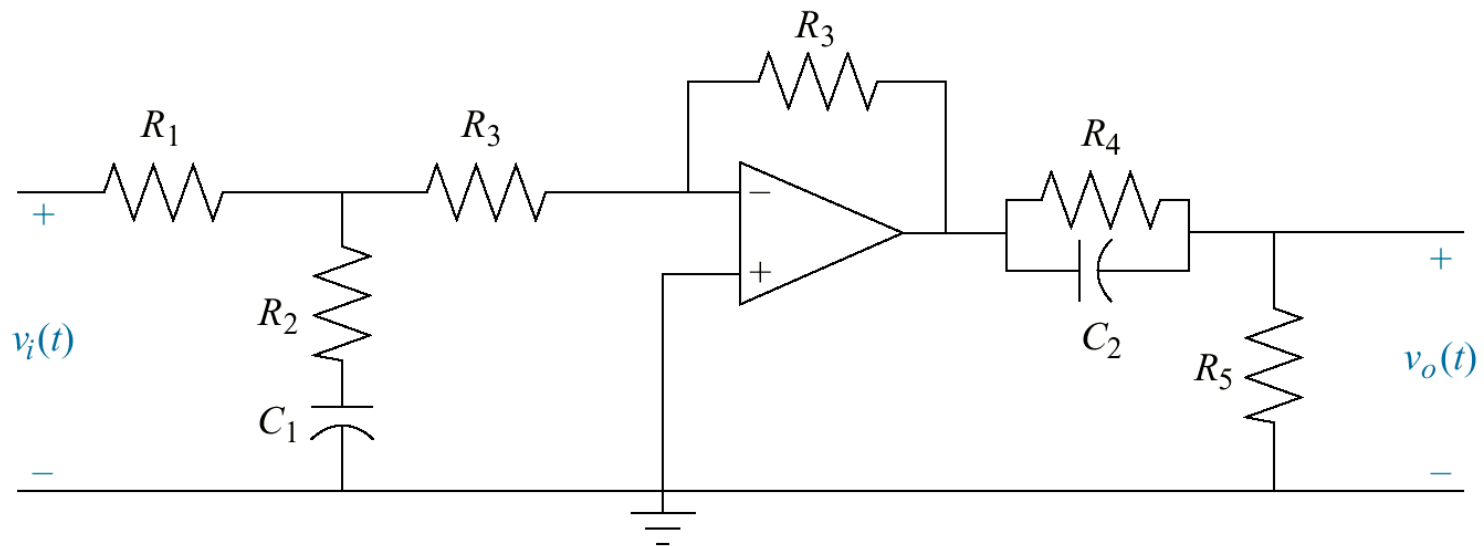
# Tabela 9.11

## Realização passiva de compensadores (slide 2 de 2)

Função	Circuito	Função de transferência	$\frac{V_o(s)}{V_i(s)}$
Compensação por atraso e avanço de fase		$\frac{\left(s + \frac{1}{R_1 C_1}\right)\left(s + \frac{1}{R_2 C_2}\right)}{s^2 + \left(\frac{1}{R_1 C_1} + \frac{1}{R_2 C_2} + \frac{1}{R_2 C_1}\right)s + \frac{1}{R_1 R_2 C_1 C_2}}$	

## Fig. 9.63

Compensador por atraso e avanço de fase implementado com associação em cascata de estruturas de atraso de fase e de avanço de fase com desacoplamento



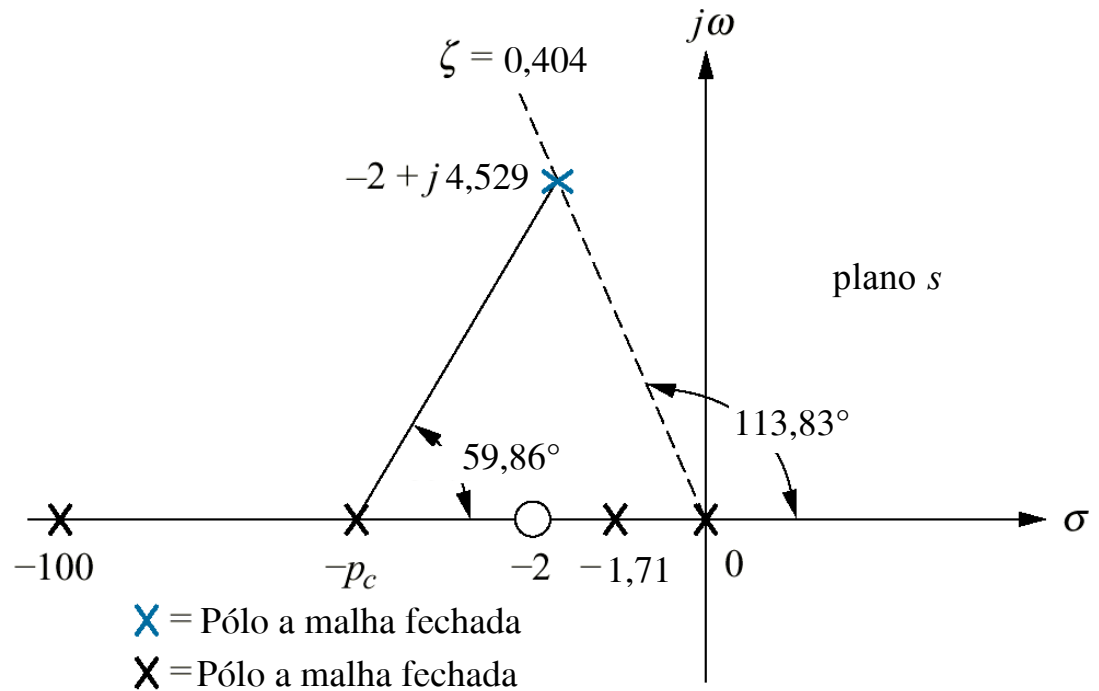
Atraso de fase

Desacoplamento

Avanço de fase

Ganho = -1

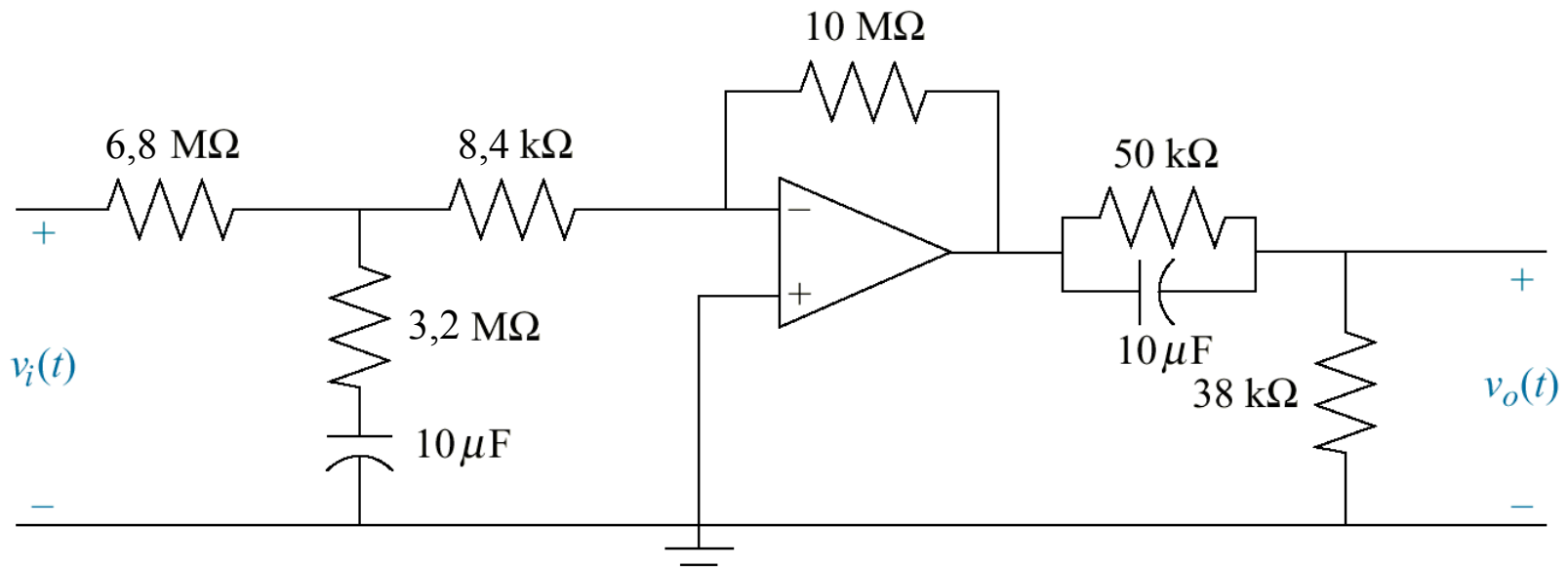
**Fig. 9.64**  
 Posicionando  
 um pólo  
 compensador



Nota: Esta figura não está desenhada em escala

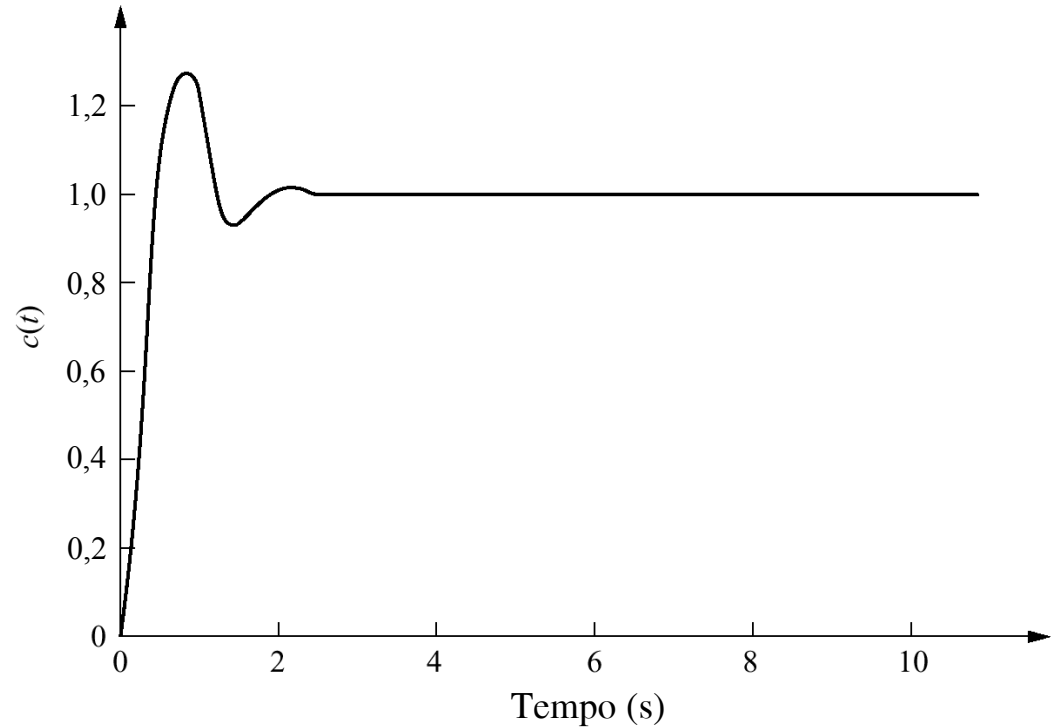
# Fig. 9.65

Implementação de compensador por atraso e avanço de fase



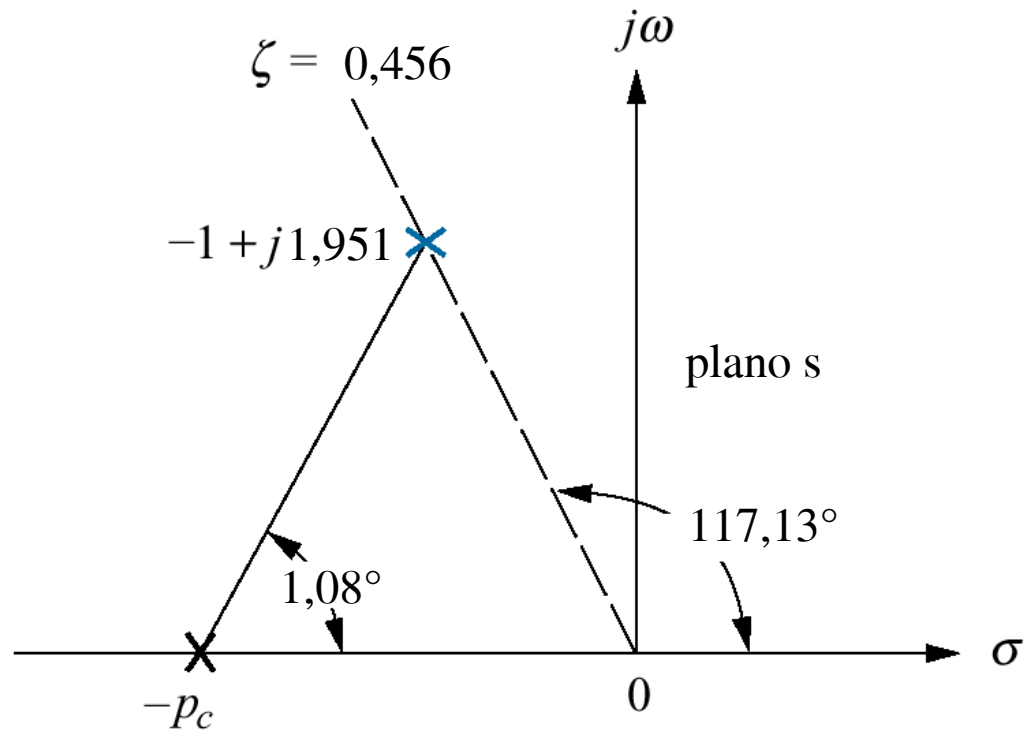
**Fig. 9.66**

Resposta ao degrau do controle de antena compensado por atraso e avanço de fase





**Fig. 9.67**  
Localizando o pólo do compensador



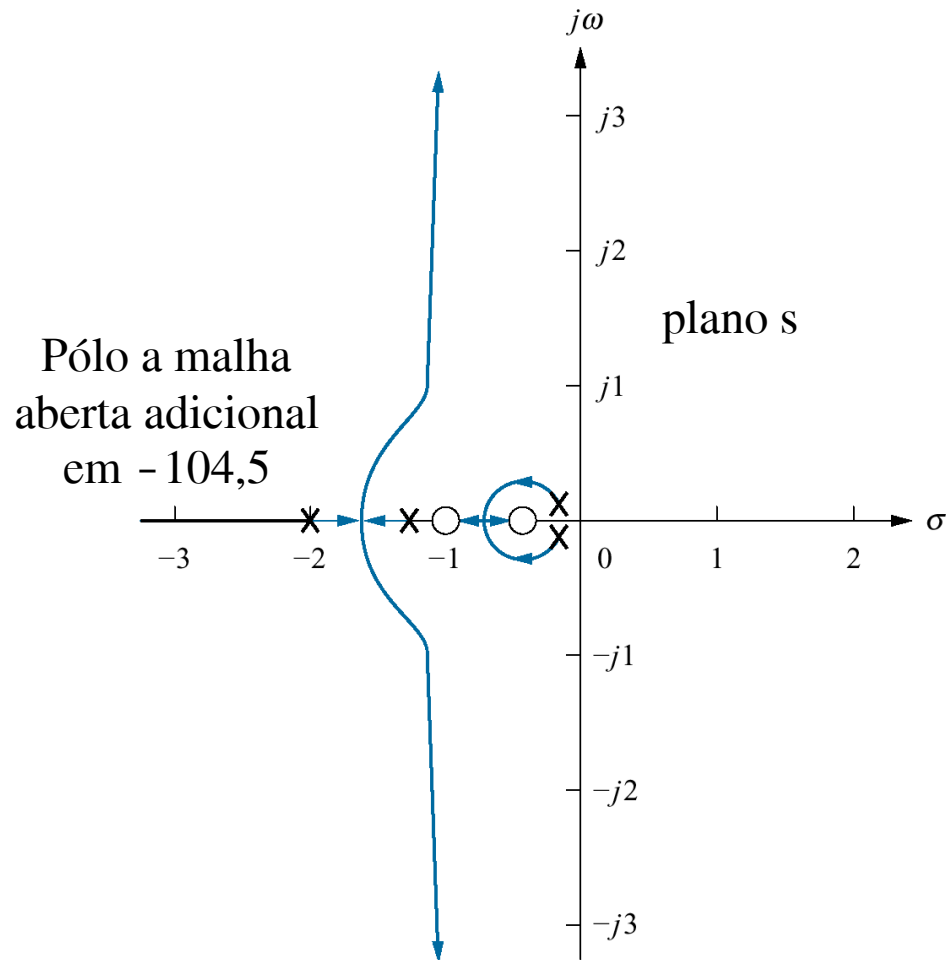
**X** = Pólo a malha fechada

**X** = Pólo a malha aberta

Nota: Esta figura não está desenhada em escala

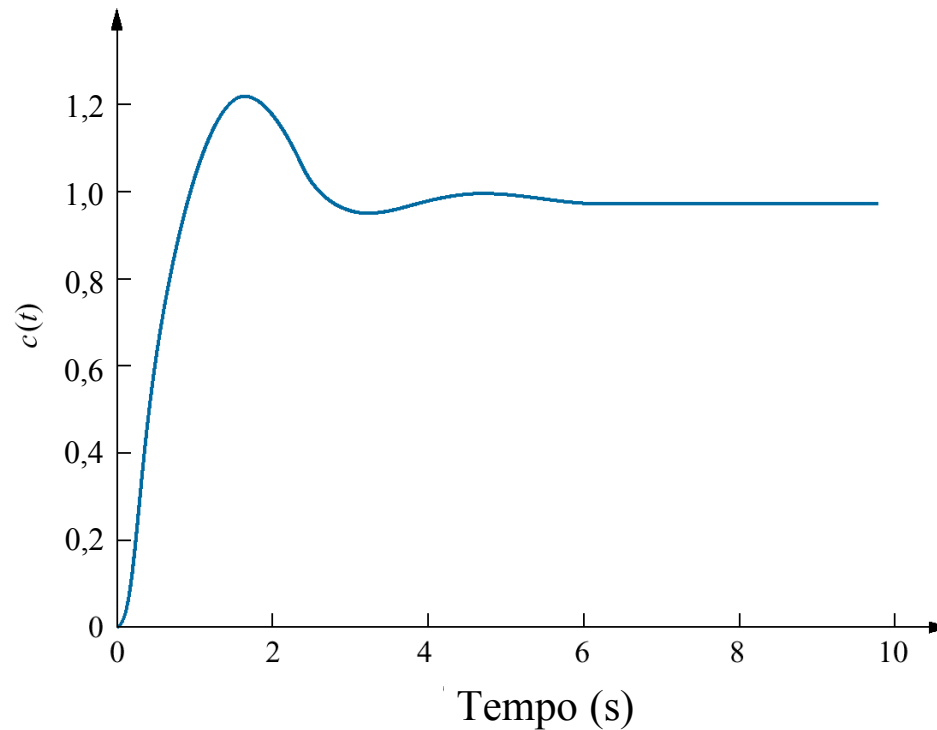
# Fig. 9.68

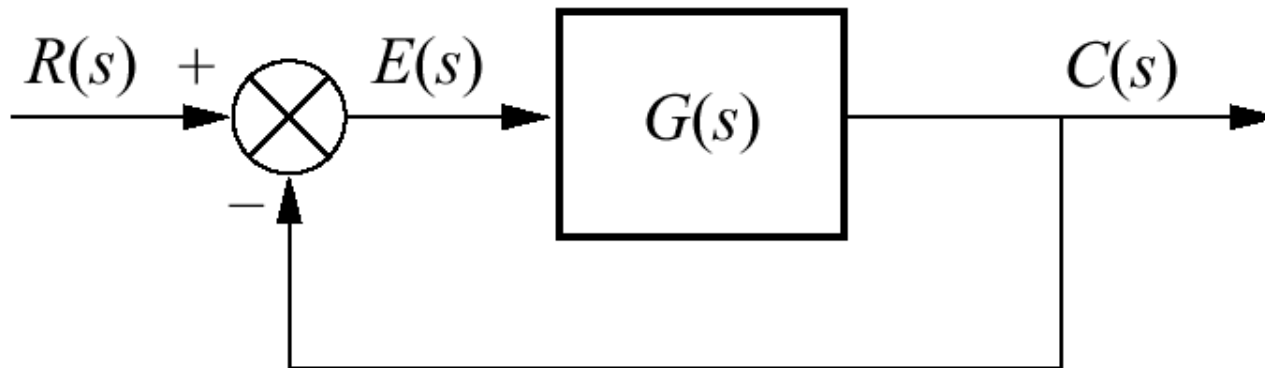
Lugar das raízes para sistema compensado por avanço de fase

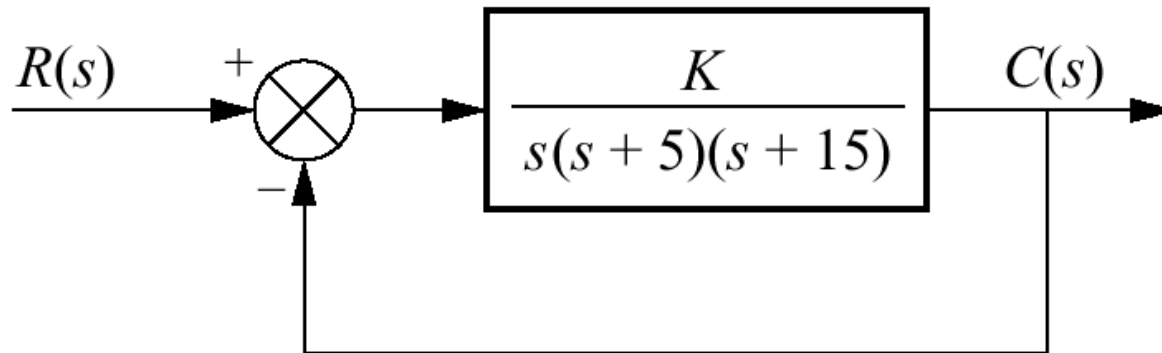


**Fig. 9.69**

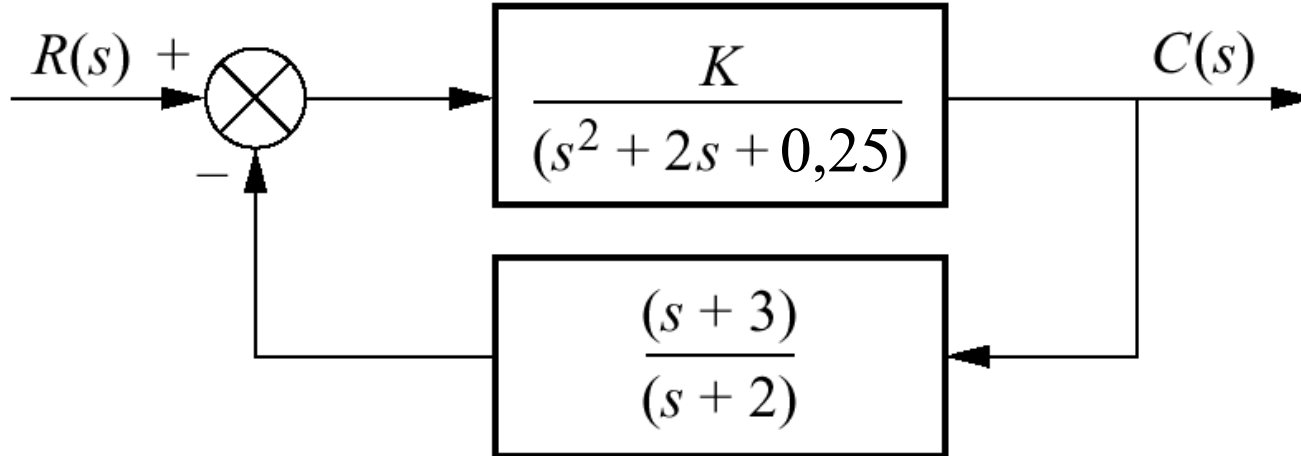
Resposta ao degrau do veículo UFSS  
compensado por avanço de fase



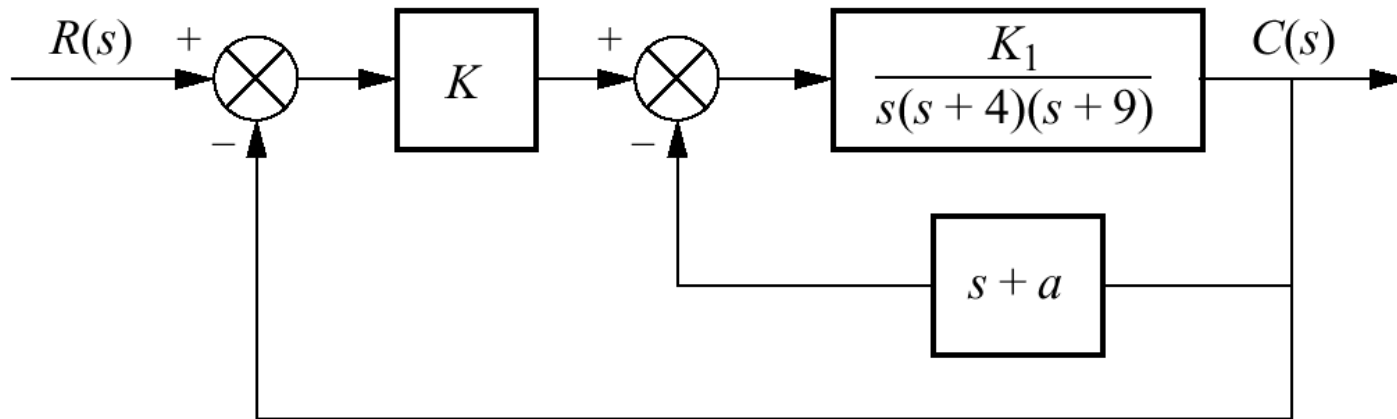
**Fig. P9.1**

**Fig. P9.2**

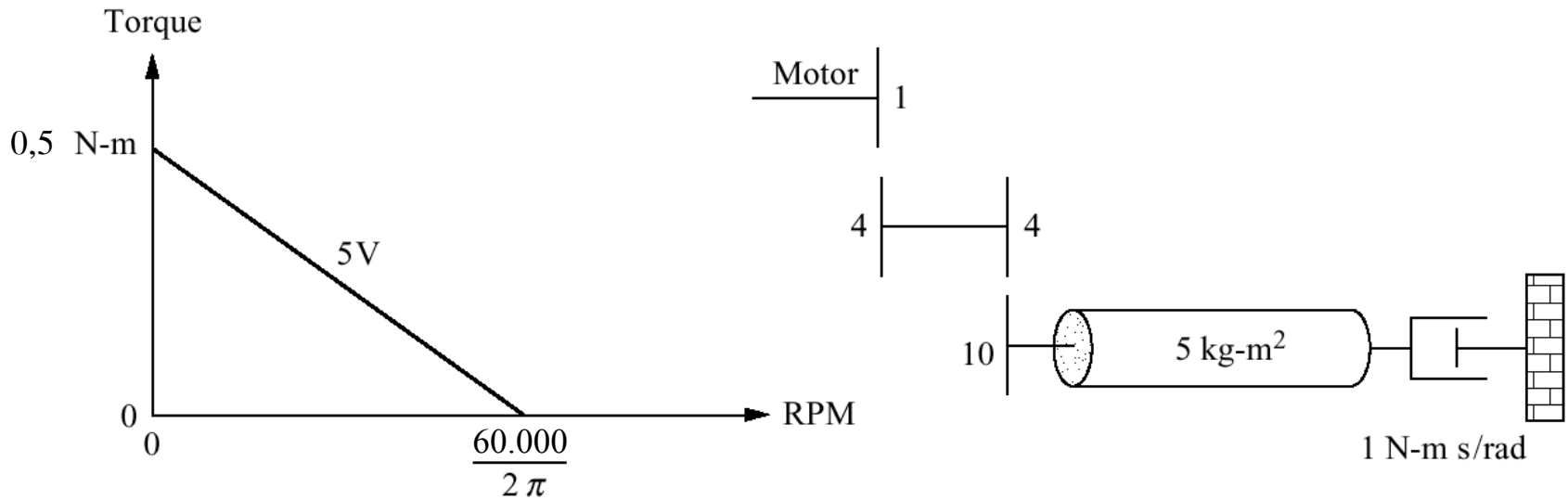
**Fig. P9.3**



**Fig. P9.4**

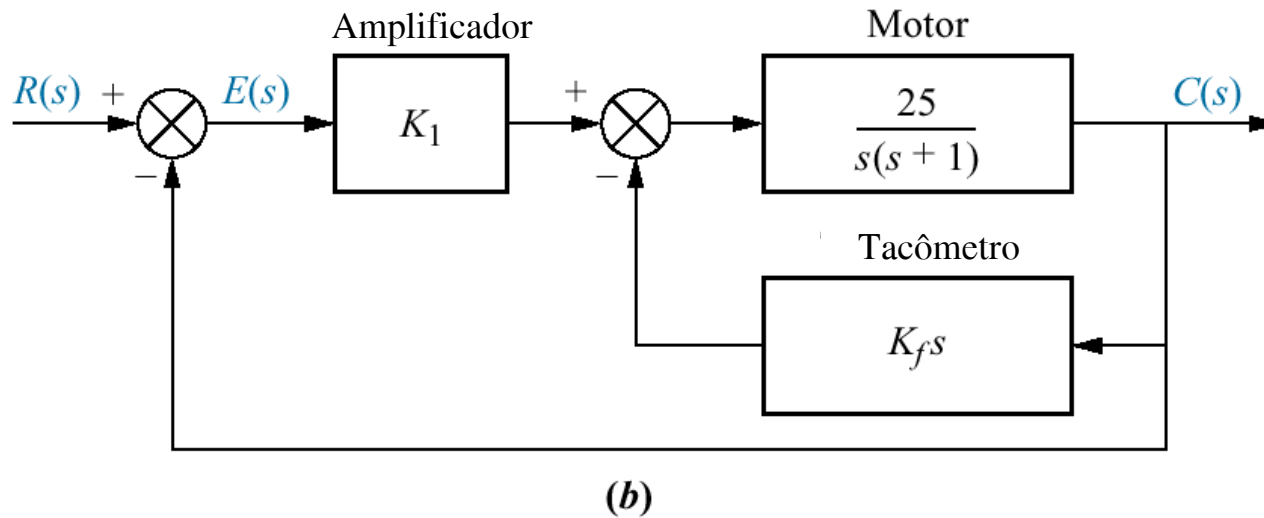
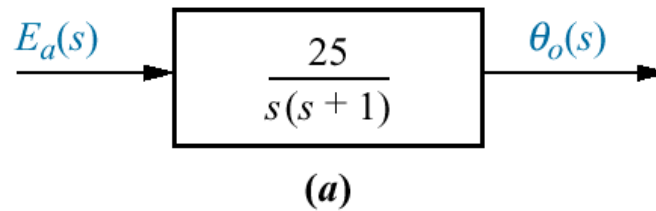


# Fig. P9.5

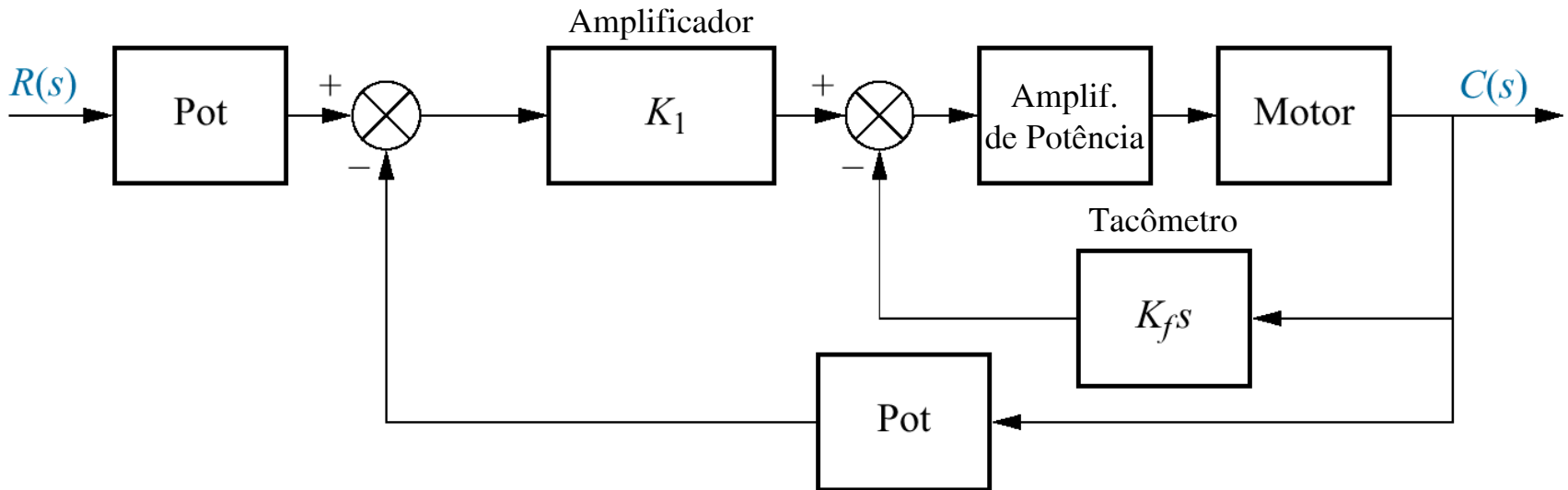




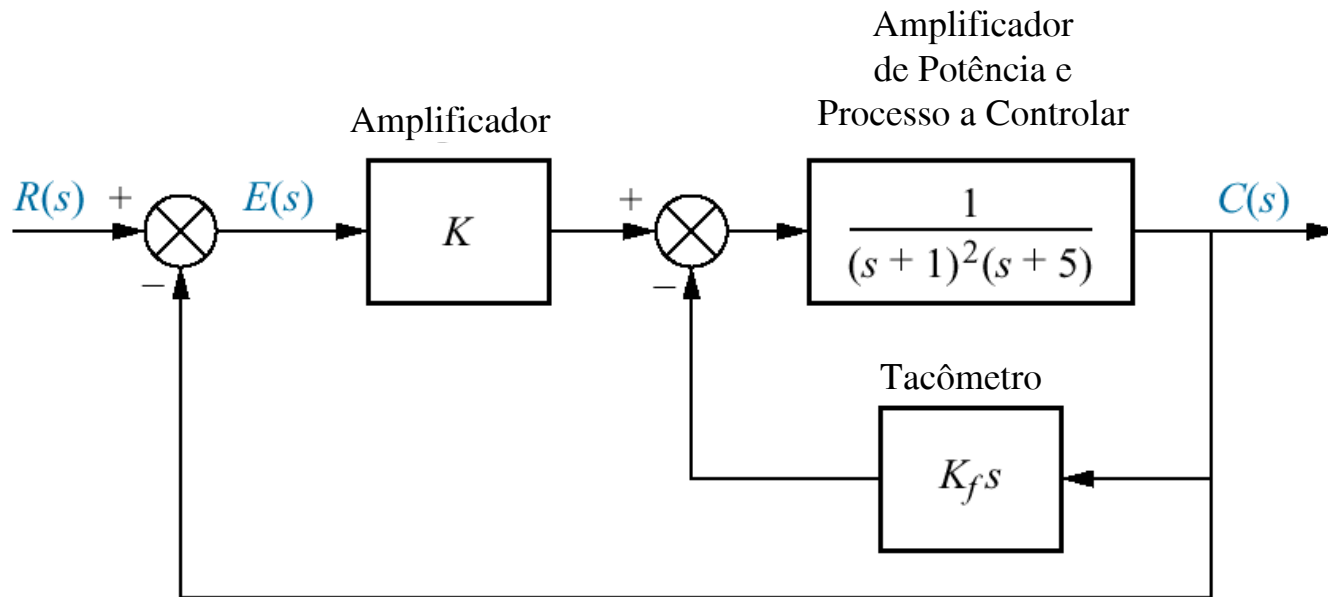
# Fig. P9.6



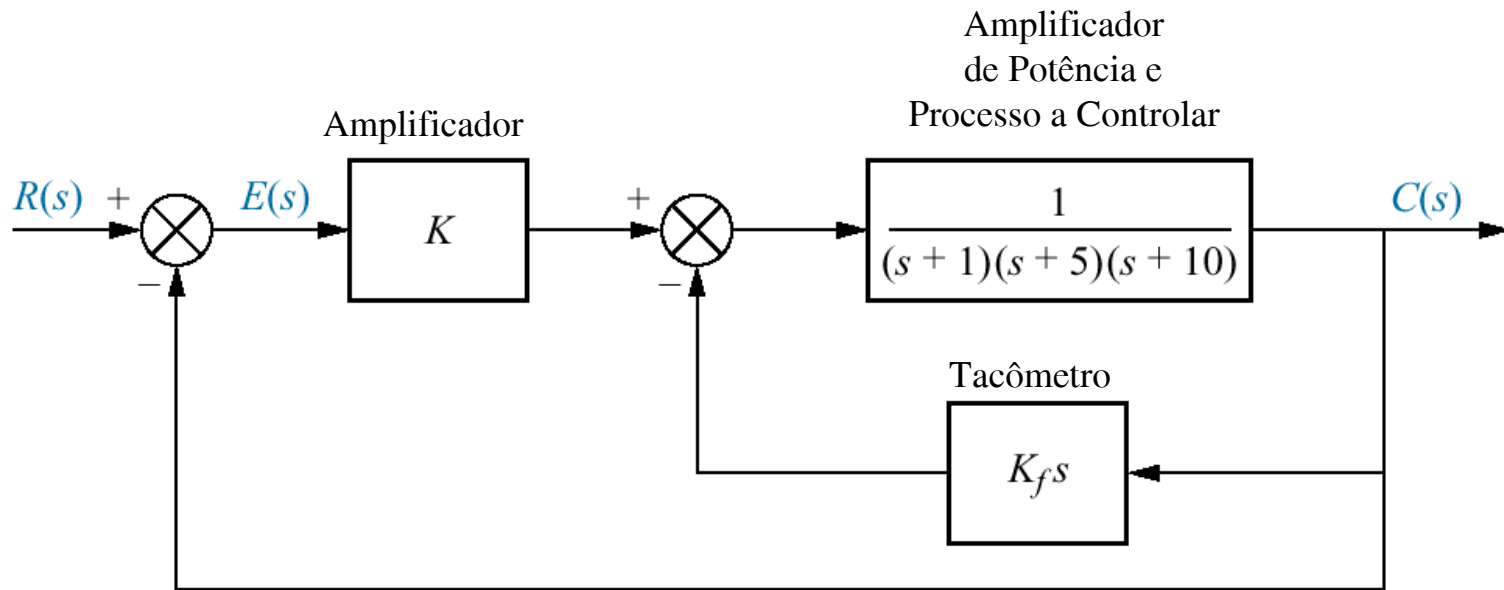
# Fig. P9.7



**Fig. P9.8**

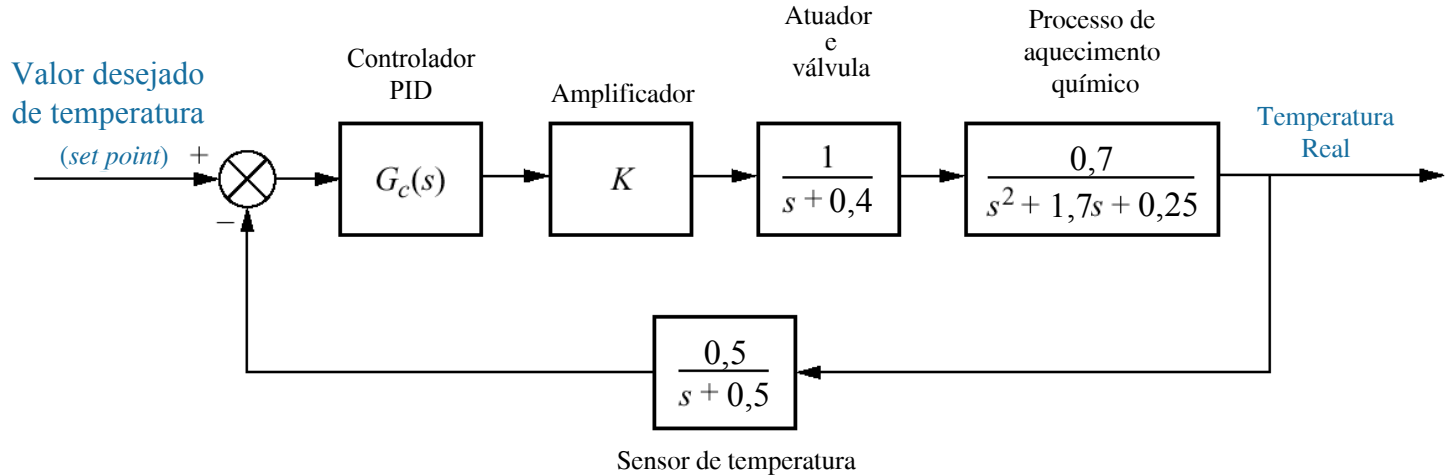


# Fig. P9.9



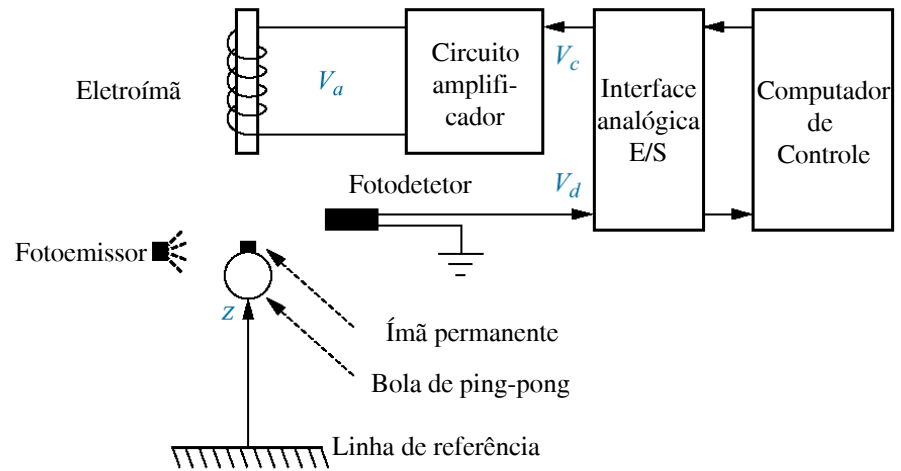
# Fig. P9.10

## Sistema de controle de temperatura de processo químico

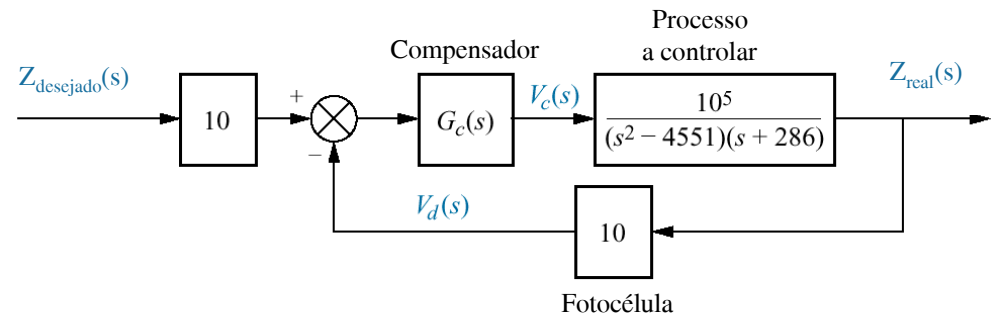


# Fig. P9.11

a. Sistema de levitação magnética (©1993 IEEE);  
 b. diagrama de blocos



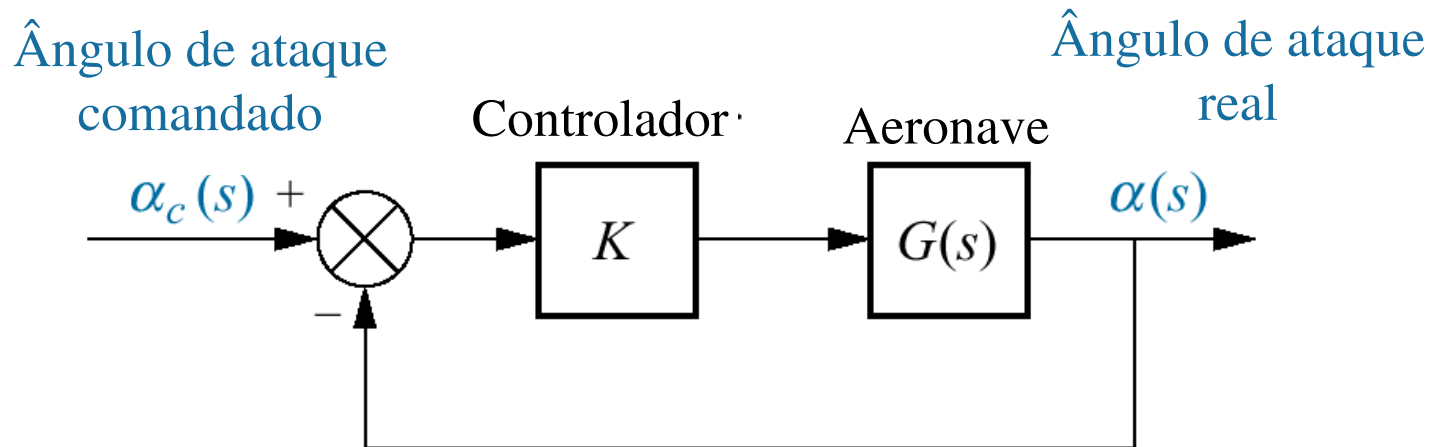
(a)



(b)

## Fig. P9.12

Diagrama de blocos simplificado para o controle do ângulo de ataque



## Fig. P9.13

Diagrama de blocos simplificado do controle do ângulo de manobra de um veículo guiado automaticamente

