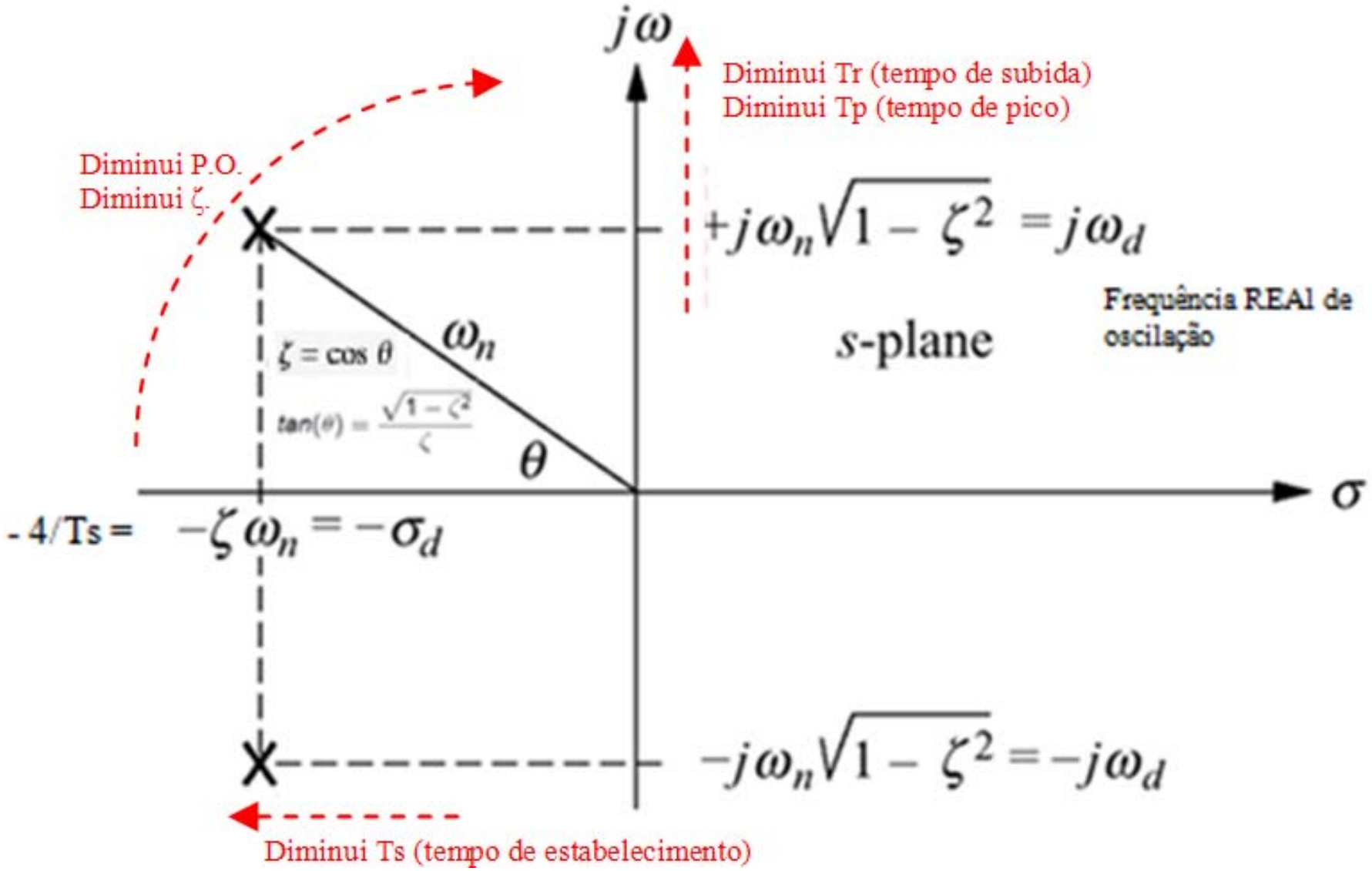
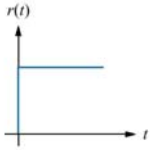
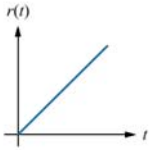
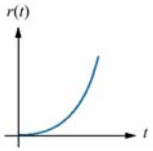
Laboratório de Projeto de Avanço e Atraso

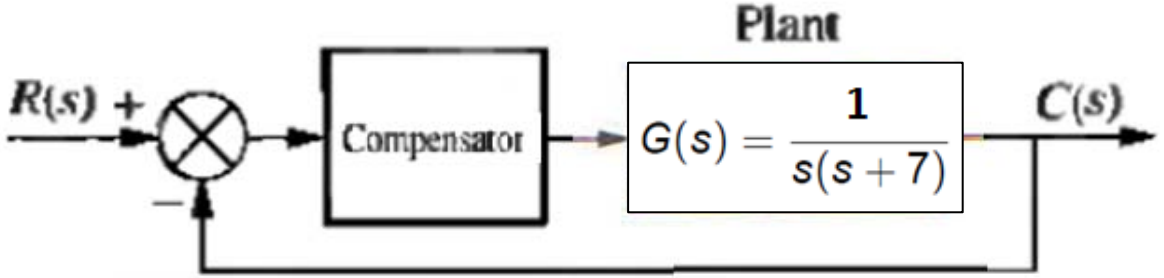
Revisão


jω
Diminui Tr (tempo de subida)
Diminui Tp (tempo de pico)
Diminui P.O.
Diminui ζ.
$+j\omega_n\sqrt{1-\zeta^2} = j\omega_d$
Frequência REAl de oscilação
s-plane
ω_n
$\zeta = \cos\theta$
$\tan(\theta) = \frac{\sqrt{1-\zeta^2}}{\zeta}$
θ
σ
- 4/Ts =
$-\zeta\omega_n = -\sigma_d$
$-j\omega_n\sqrt{1-\zeta^2} = -j\omega_d$
Diminui Ts (tempo de estabelecimento)

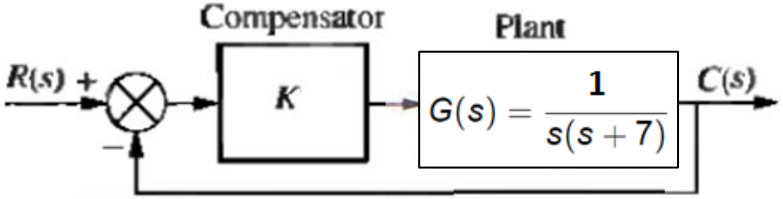
Entrada		Expressão do erro estacionário	
Degrau $u(t)$		$\frac{1}{1+K_p}$	$K_p = \lim_{s\to 0} G(s)$
Rampa, $tu(t)$		$\frac{1}{K_v}$	$K_v = \lim_{s\to 0} sG(s)$
Parábola, $\frac{1}{2}t^2u(t)$		$\frac{1}{K_a}$	$K_a = \lim_{s\to 0} s^2G(s)$

Exercício 1 - Controlador de Atraso

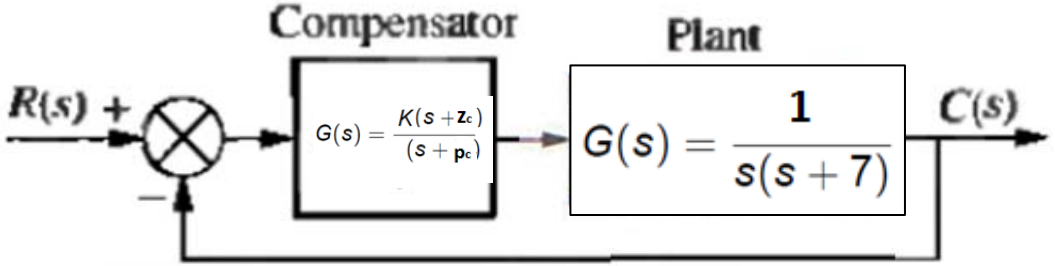
Dado o sistema:



No Matlab projete um compensador ***P*** para conseguir um P.O. de 15%.

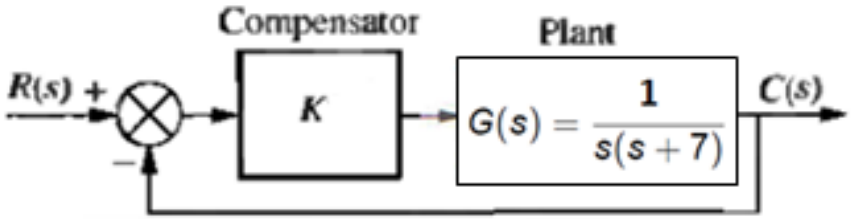


No Matlab projete um compensador de **Atraso** com p_c = 0,01 e erro 20 vezes menor do que o controlador ***P***.



Comparar a resposta ao degrau e a rampa, os ganhos K e os erros de estado estacionário.

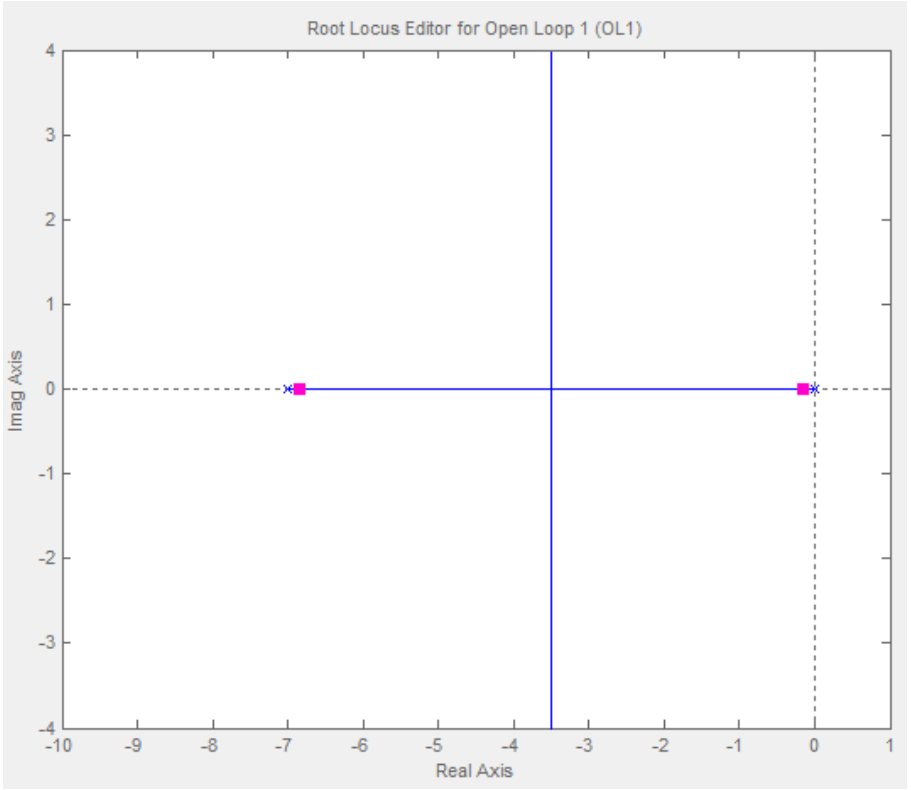
Exercício 1 – Resposta



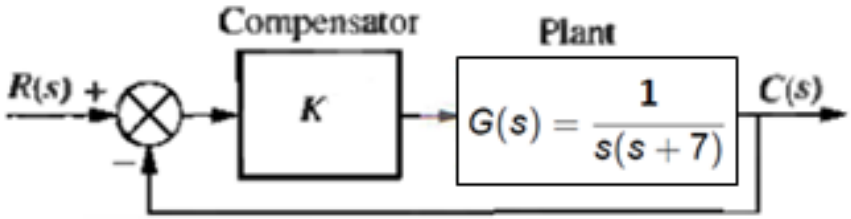
Sistema não compensado

Root Locus

```
>> s = tf('s');
>> gs_desc = 1/(s*(s+7));
>> sys = feedback(gs_desc,1)
>> rltool(gs_desc)
%sisotool para root locus
```

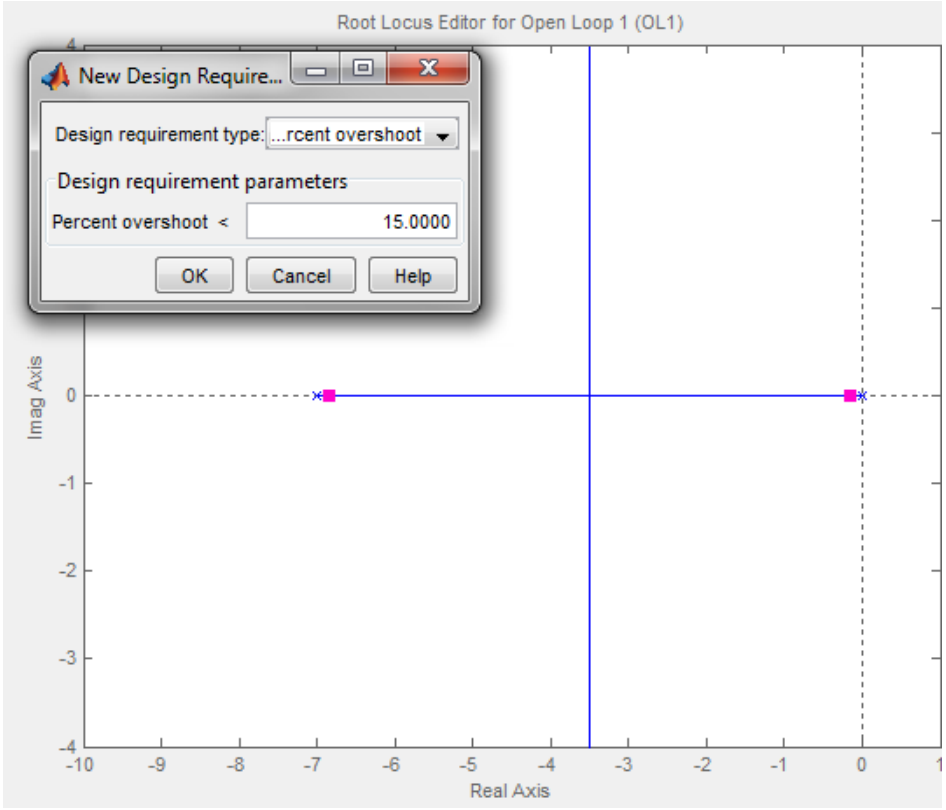


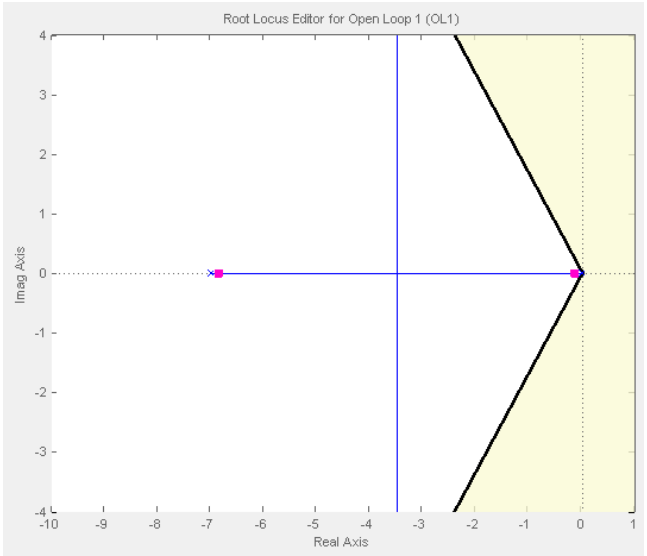
Exercício 1 – Resposta



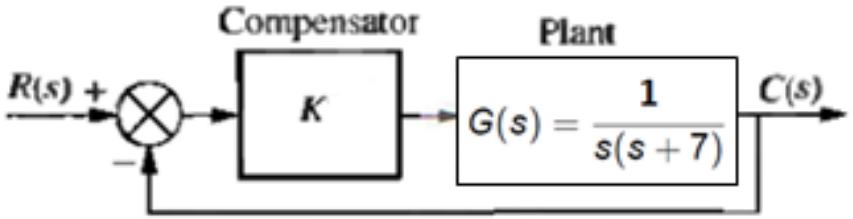
Sistema não compensado

Delimitando PO = 15%

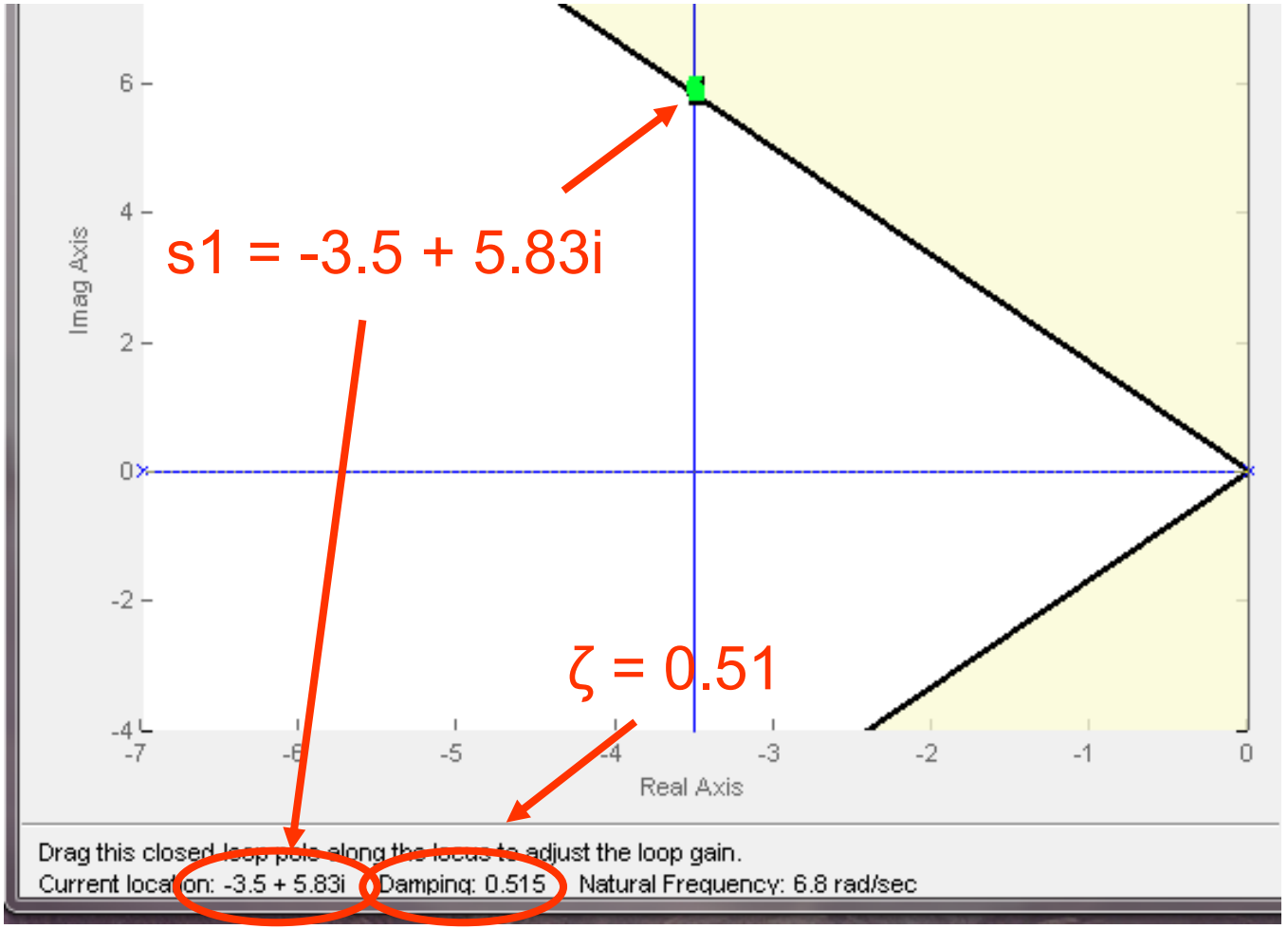




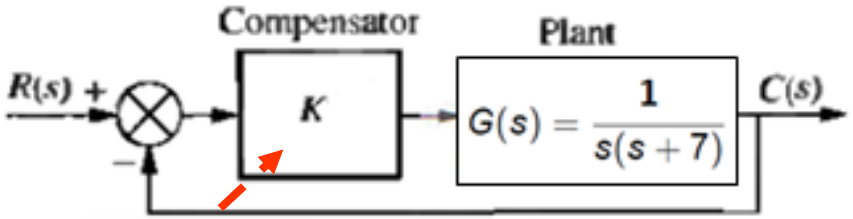
Exercício 1 – Resposta



Sistema não compensado



Exercício 1 – Resposta



Sistema não compensado

Condição de pertencer ao Root Locus

$$|G(s)| = 1 \longrightarrow K = 46.23$$

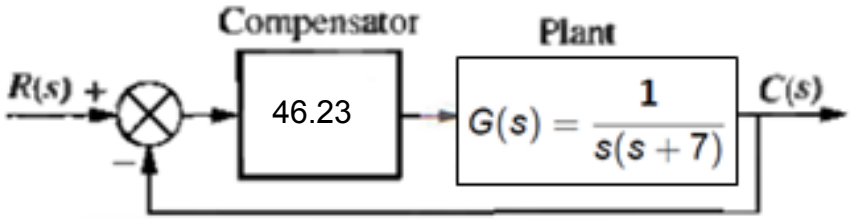
s = s1 = -3.5 + 5.83i

```
>> s1 = -3.5 + 5.83i

>> k = abs(s1*(s1+7))
```

K = 46.23

Exercício 1 – Resposta



Sistema não compensado

Condição de pertencer ao Root Locus

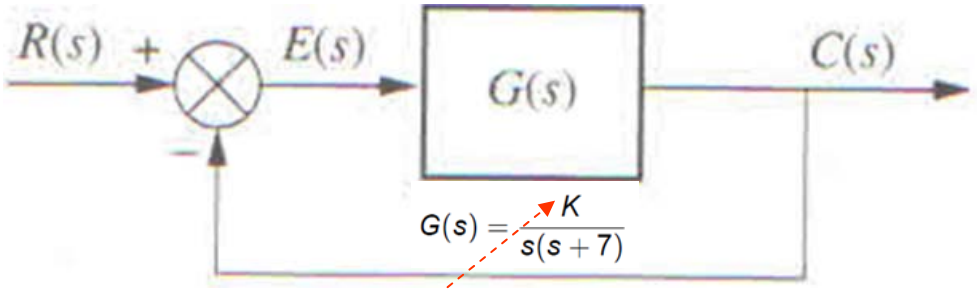
Entrada	Expressão do erro estacionário
Rampa, $tu(t)$	 $\frac{1}{K_v}$

$$K_v = \lim_{s \to 0} sG(s)$$

$$Kv = \frac{46.23}{(0+7)} = 6.6$$

$$Erro(ramp) = \frac{1}{6.6} = 0{,}15$$

Exercício 1 – Resposta



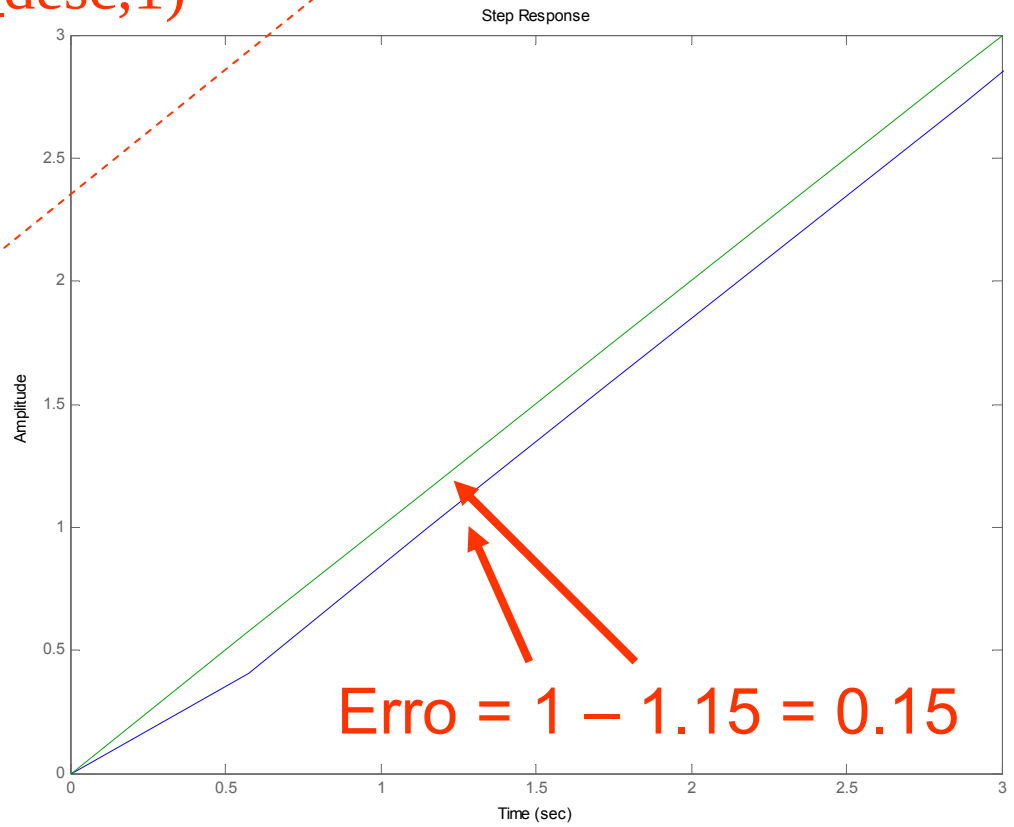
Sistema não compensado

Resposta a rampa

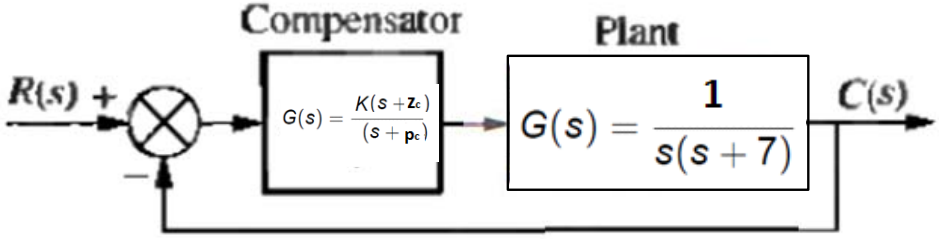
```
>> gs_desc = 1/(s*(s+7));
>> sys = feedback(46.23*gs_desc,1)
>> step(sys/s)
%Plota a resposta a rampa
>> hold on
%Congela a figura
>> step(1/s)
% Plota a rampa original
```

Transfer function:

$$\frac{46.23}{s^2 + 7s + 46.23}$$



Exercício 1 – Resposta



Sistema compensado

Entrada	Expressão do erro estacionário
Rampa, $tu(t)$	$\frac{1}{K_v}$

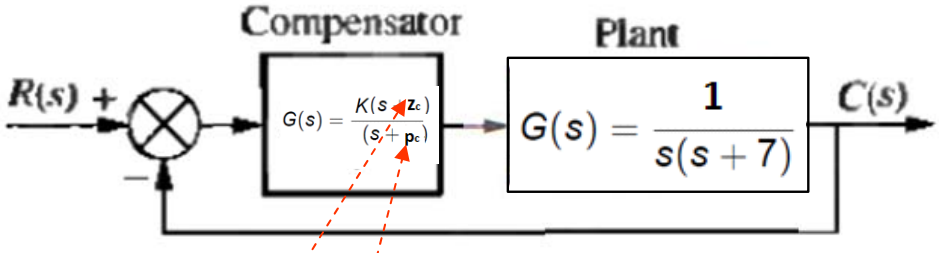
$$K_v = \lim_{s \to 0} sG(s)$$

$$Erro\_comp = \frac{0,15}{20} = 0,0075$$

$$Erro\_comp = 0,0075 = \frac{1}{Kv}$$

$$\Rightarrow Kv\_comp = \frac{1}{(0,0075)} = 133.3$$

Exercício 1 – Resposta



Sistema compensado

Entrada	Expressão do erro estacionário
Rampa, $tu(t)$	$\frac{1}{K_v}$ $\quad K_v = \lim_{s\to 0} sG(s)$

$$\frac{z_c}{p_c} = \frac{k_{comp}}{k_{desc}} = \frac{133}{6,6} = 20$$

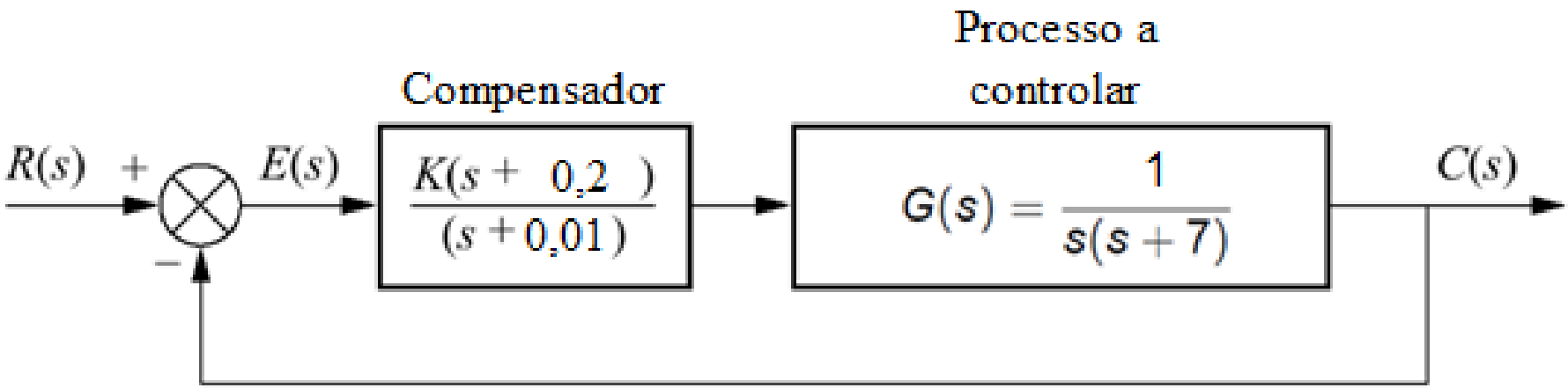
Selecionando arbitrariamente: $p_{comp} = 0,01$

$$20 = \frac{z_c}{0,01} \Rightarrow z_c = 0,2$$

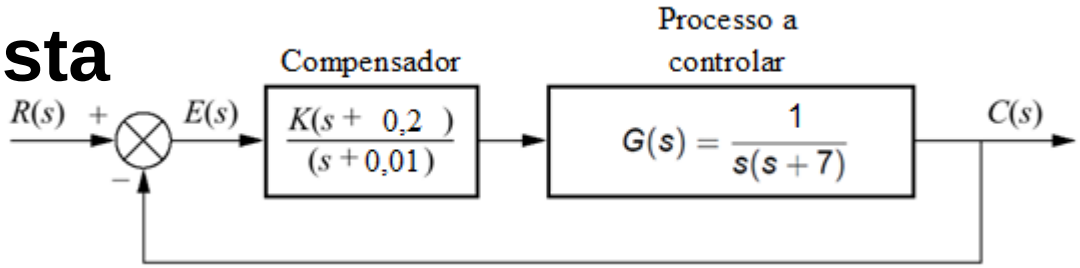
Exercício 1 – Resposta

Sistema compensado

Compensador



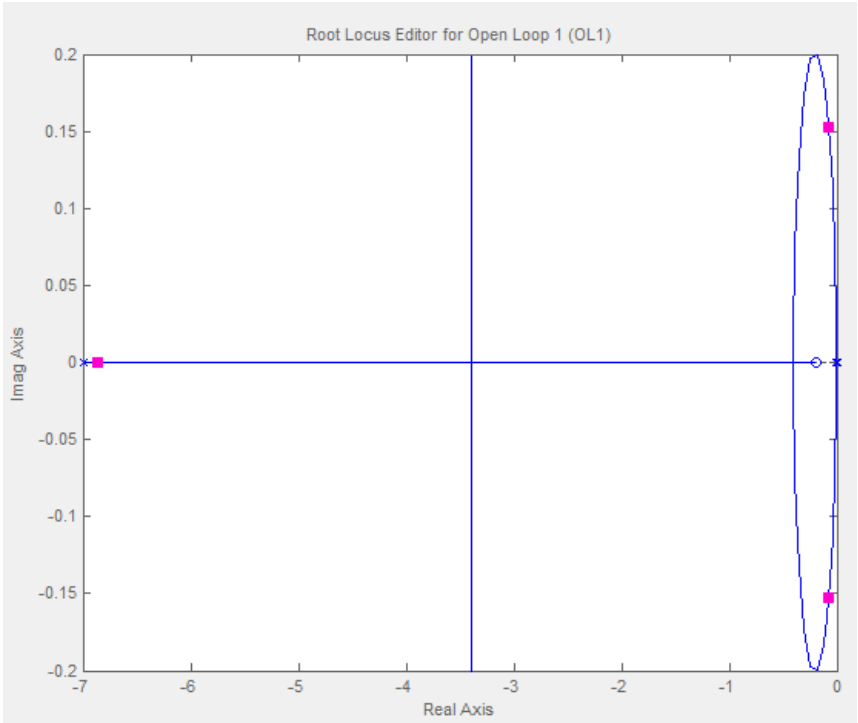
Exercício 1 – Resposta



Sistema compensado

Root Locus

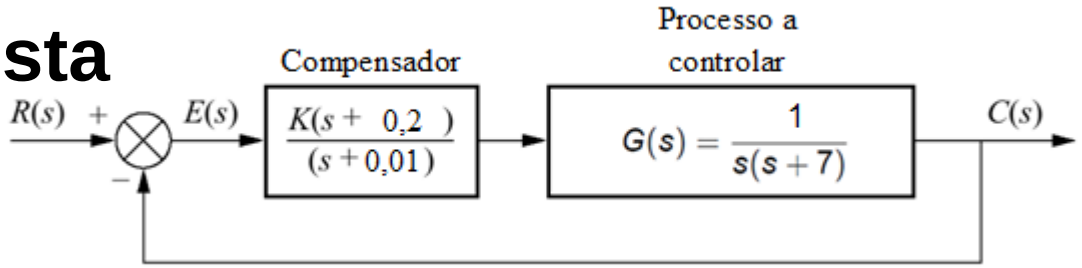
```
>> gs_comp = (s+0.2)/((s+0.01)*s*(s+7));
>> rltool(gs_comp) %sisotool para root locus
```



Transfer function:

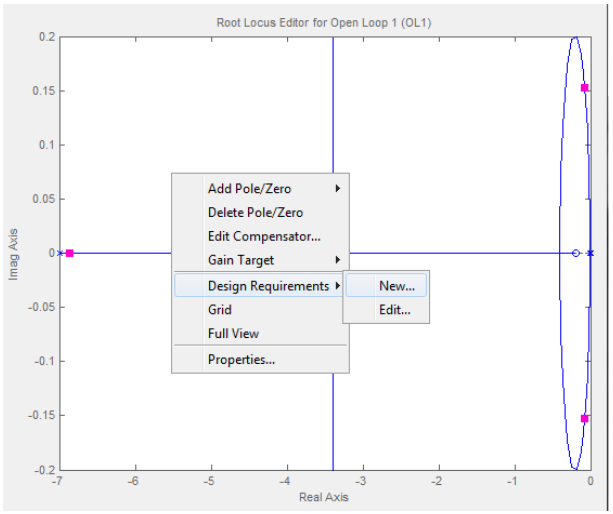
$$\frac{s + 0.2}{s^3 + 7.01\,s^2 + 1.07\,s + 0.2}$$

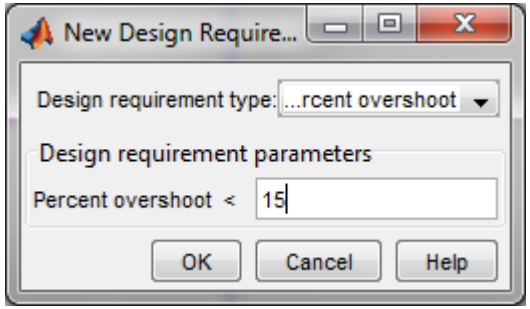
Exercício 1 – Resposta

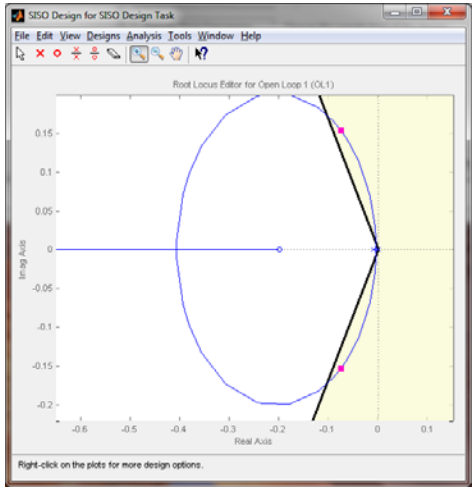


Sistema compensado

Delimitando PO = 15%

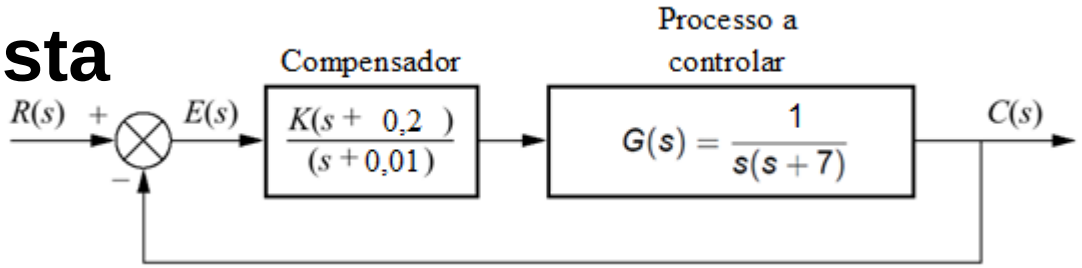


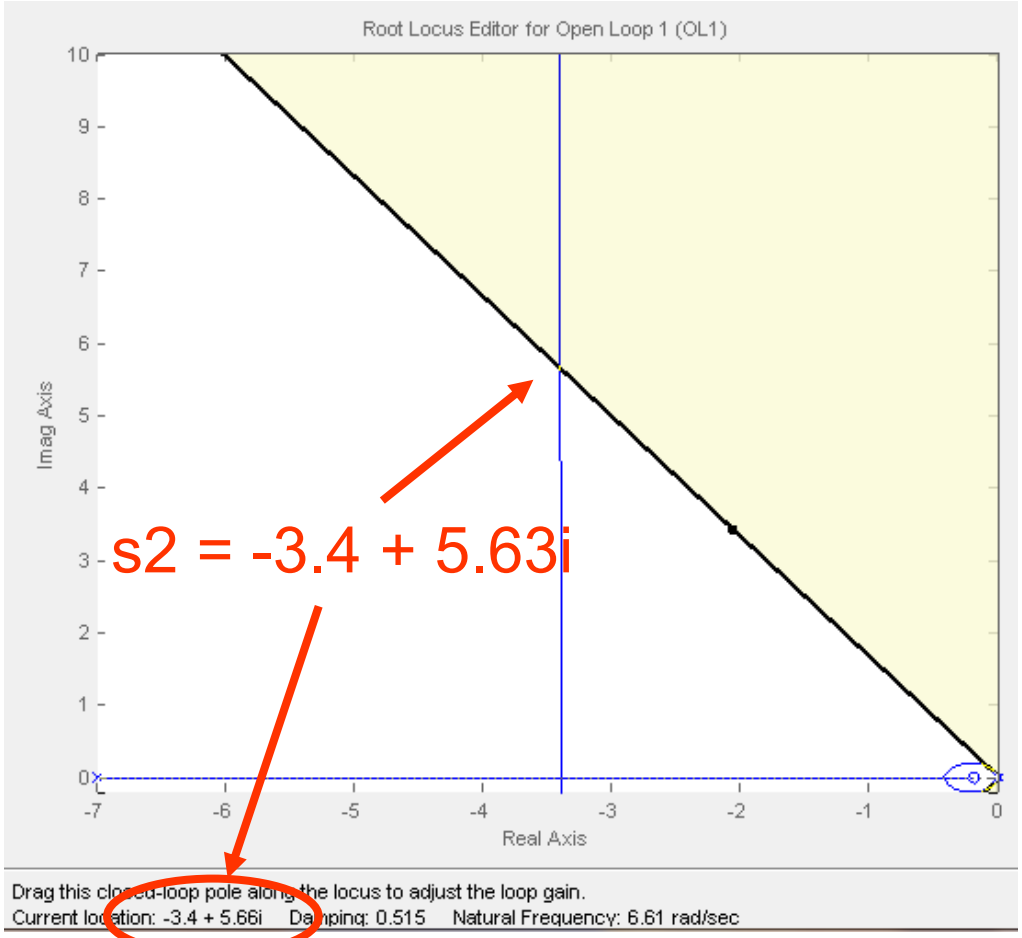




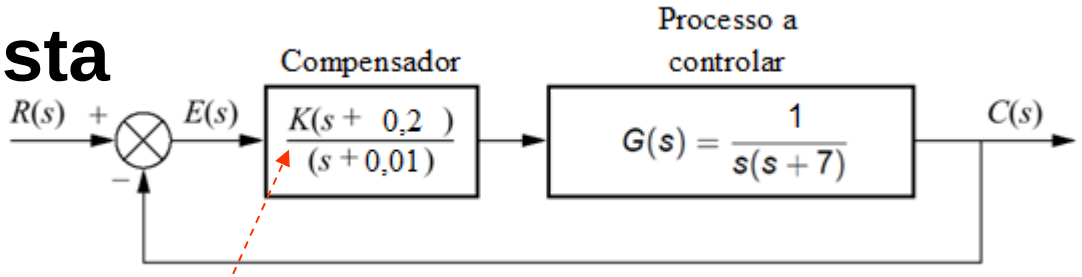
Exercício 1 – Resposta

Sistema compensado





Exercício 1 – Resposta



Sistema compensado

Condição de pertencer ao Root Locus

$$|G(s)| = 1 \longrightarrow K = 44.6$$

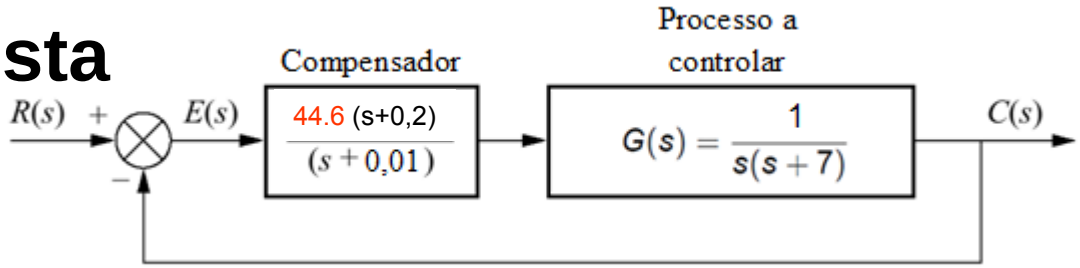
s = s2 = -3.4 + 5.63i

```
>> s2 = -3.4 + 5.63i

>> k_comp = abs(s2*(s2+7)*(s2+0.01)/(s2+0.2))
```

K_comp = 44.6

Exercício 1 – Resposta



Sistema compensado

Resposta a rampa

```
>> gs_comp = (s+0.2)/((s+0.01)*s*(s+7));
>> sys_comp = feedback(44.6*gs_comp,1)
>> step(sys_comp/s)
%Plota a resposta a rampa
>> hold on
%Congela a figura
>> step(1/s)
% Plota a rampa original
>> step(sys/s) %Plota sistema não compensado
>> legend('Compensado','rampa', 'não compensado')
```

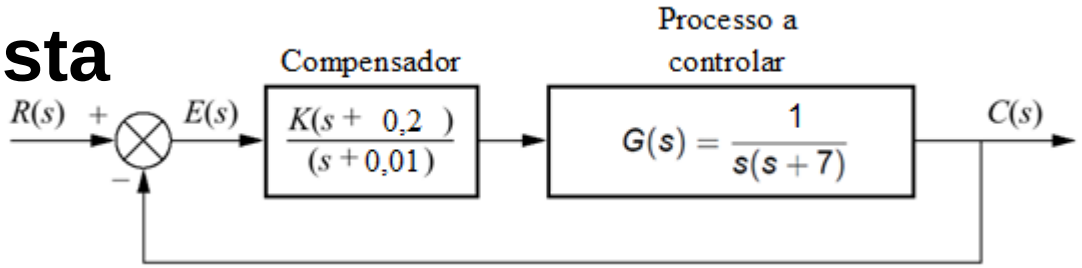
Transfer function:

1.35 s + 0.27

---

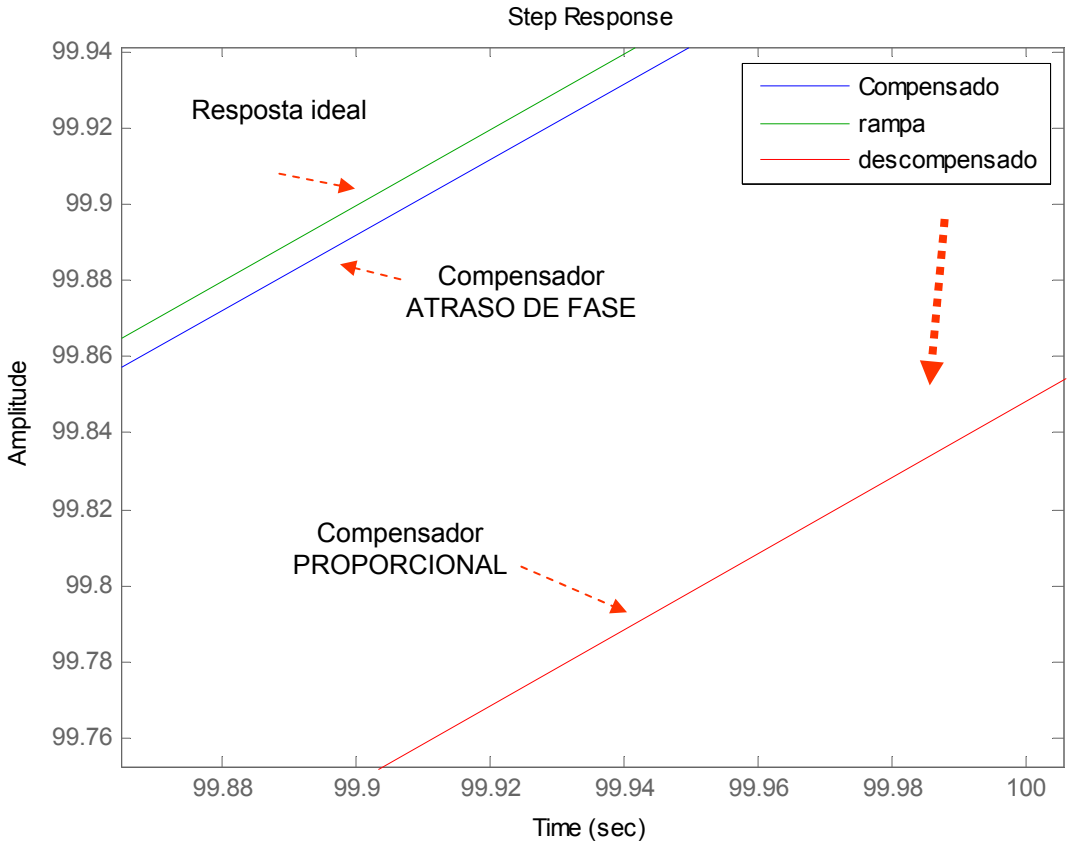
s^3 + 7.01 s^2 + 1.42 s + 0.27

Exercício 1 – Resposta



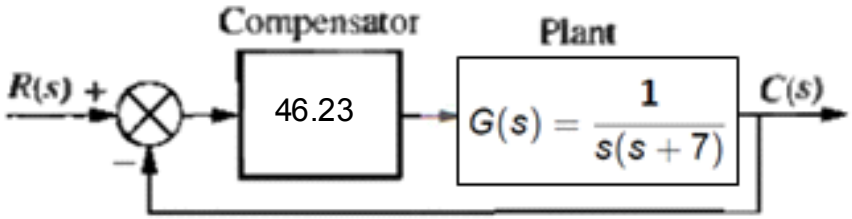
Sistema compensado

Resposta a rampa

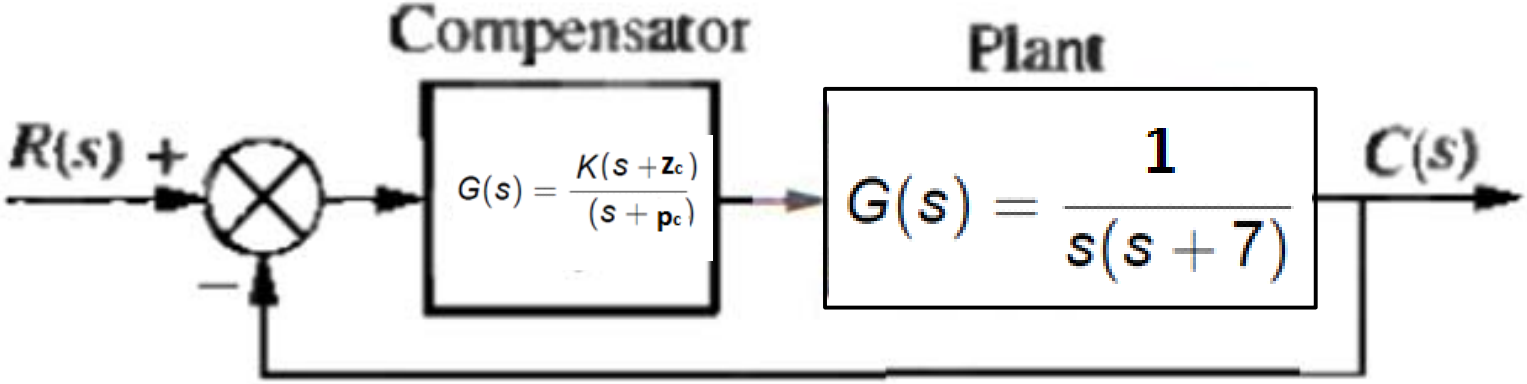


Exercício 2 - Controlador de Avanço

Dado o sistema o mesmo sistema do Exercício 1 e mesmo P.O. de 15 %:

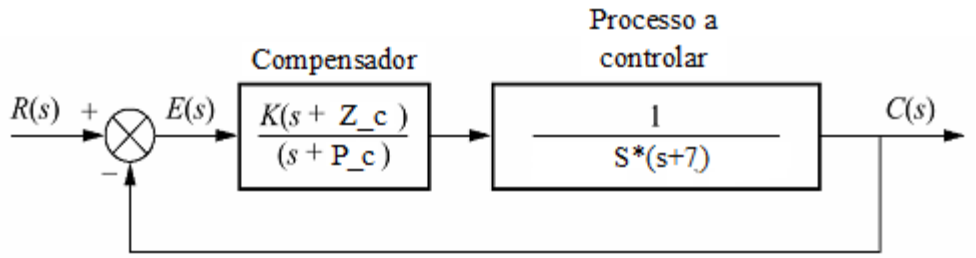


No Matlab projete um compensador de **Avanço** com tempo de stabelecimento 3 vezes menor do que o sistema acima. Adote *Zc* = 10.



Comparar a resposta ao degrau e a rampa, os ganhos K e os erros de estado estacionário.

Exercício 2 – Resposta



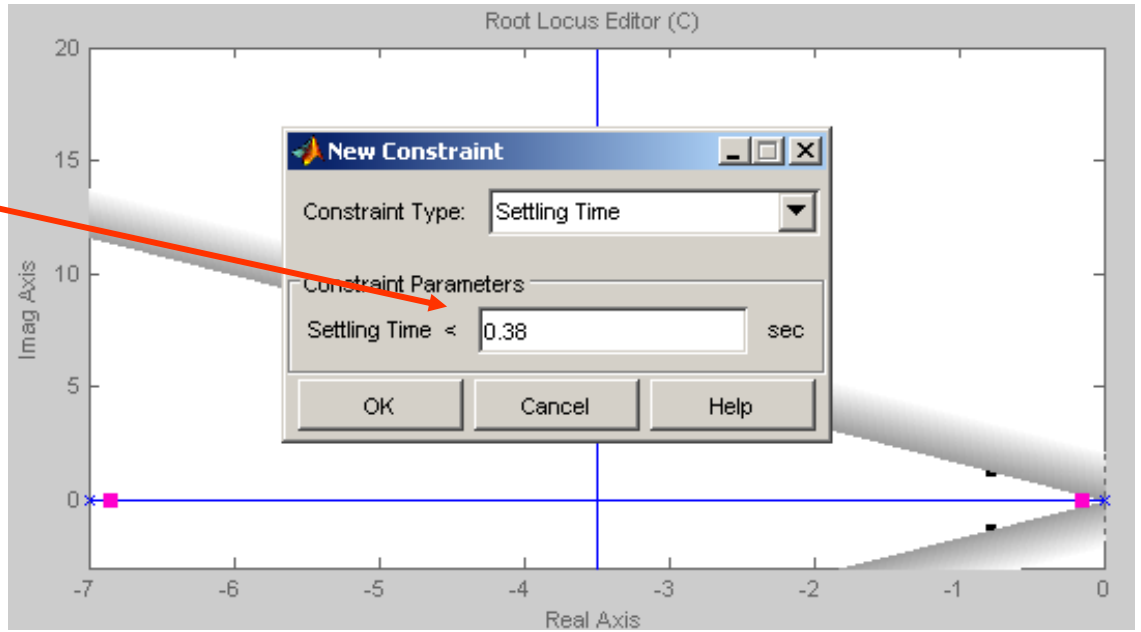
Sistema compensado

Usando os dados do exercicio 1:

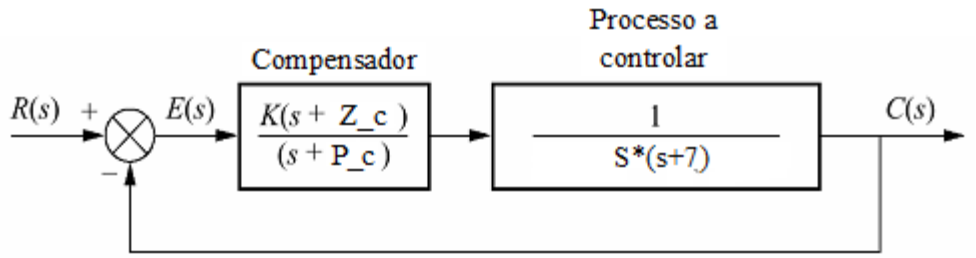
|Re|=3,5 logo,

$$Te = \frac{4}{\varsigma w_n} = \frac{4}{3.5} = 1{,}14 seg.$$

$$Te' = \frac{Te}{3} = 0.38 seg.$$

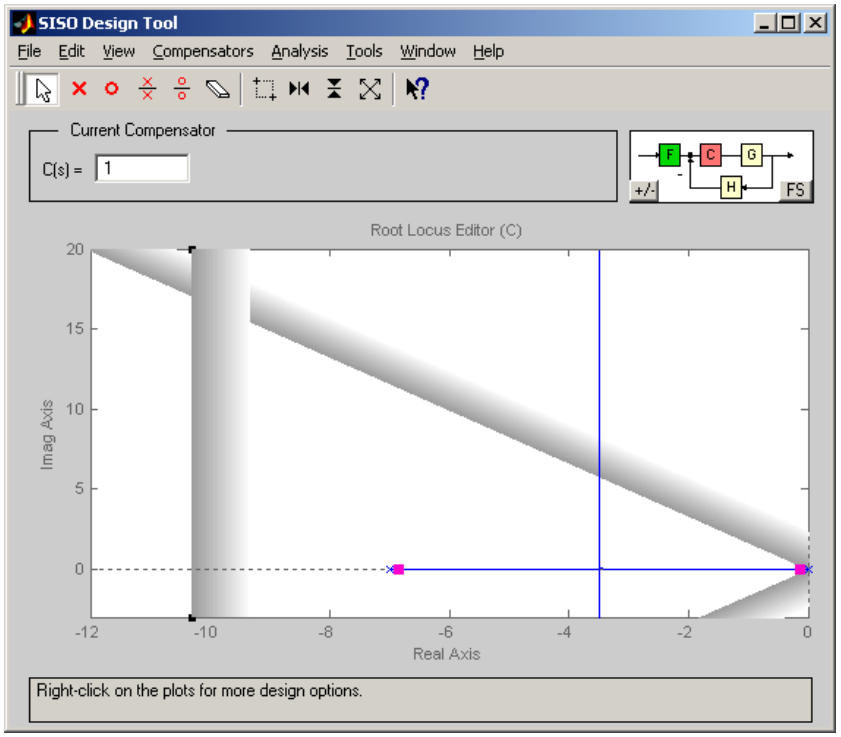


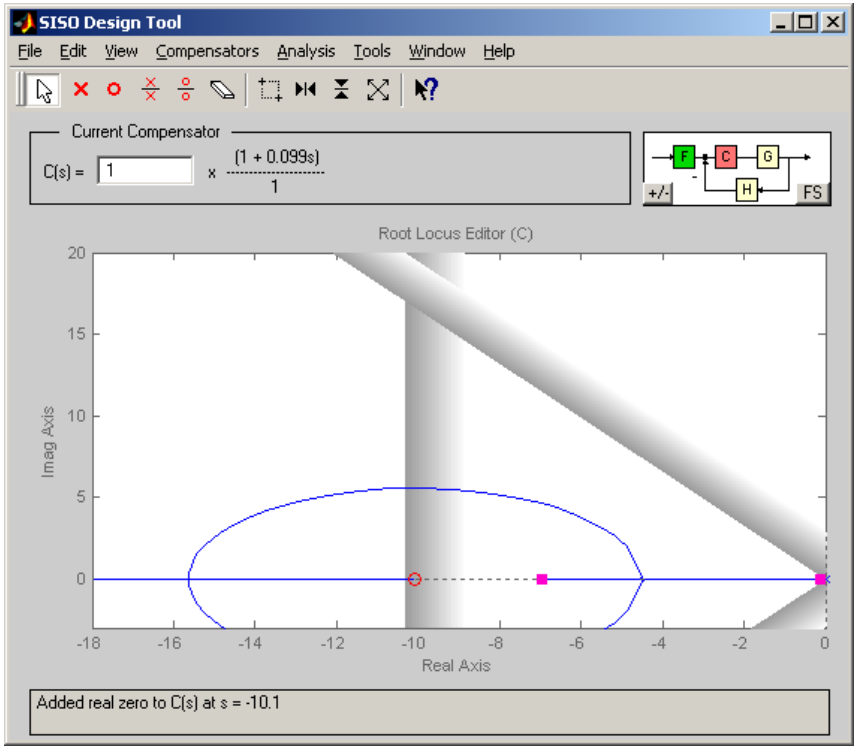
Exercício 2 – Resposta



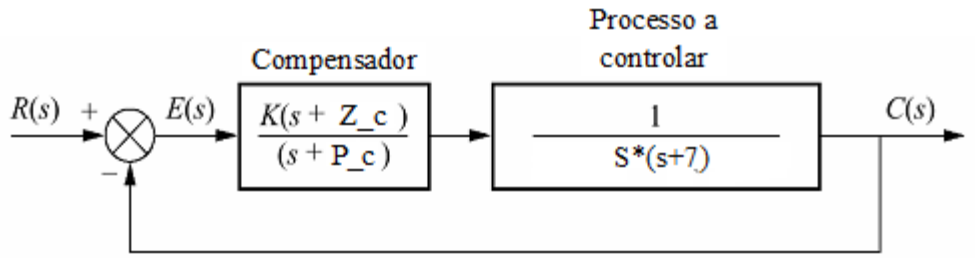
Sistema compensado

Adiciona-se um zero em -10



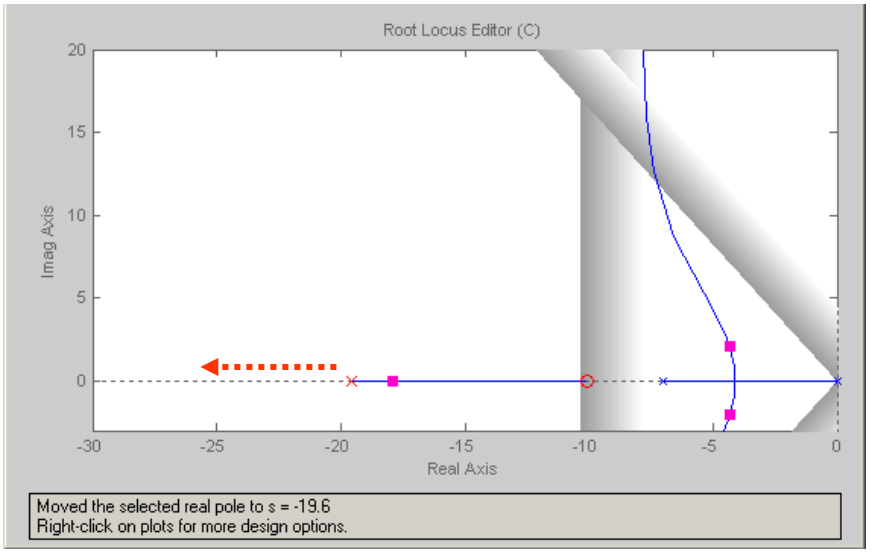


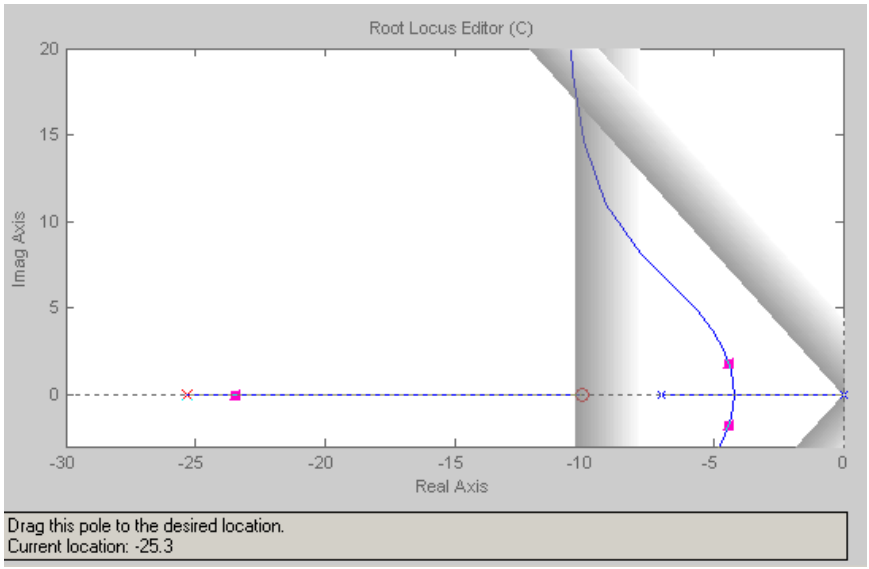
Exercício 2 – Resposta



Sistema compensado

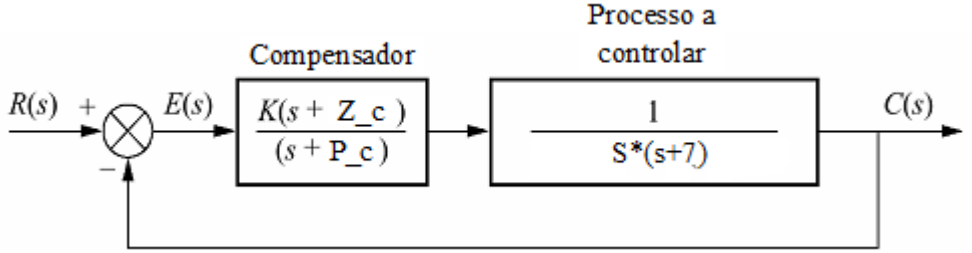
Adiciona-se um polo e muda sua posição até a intercessão com as retas do P.O. e do Te

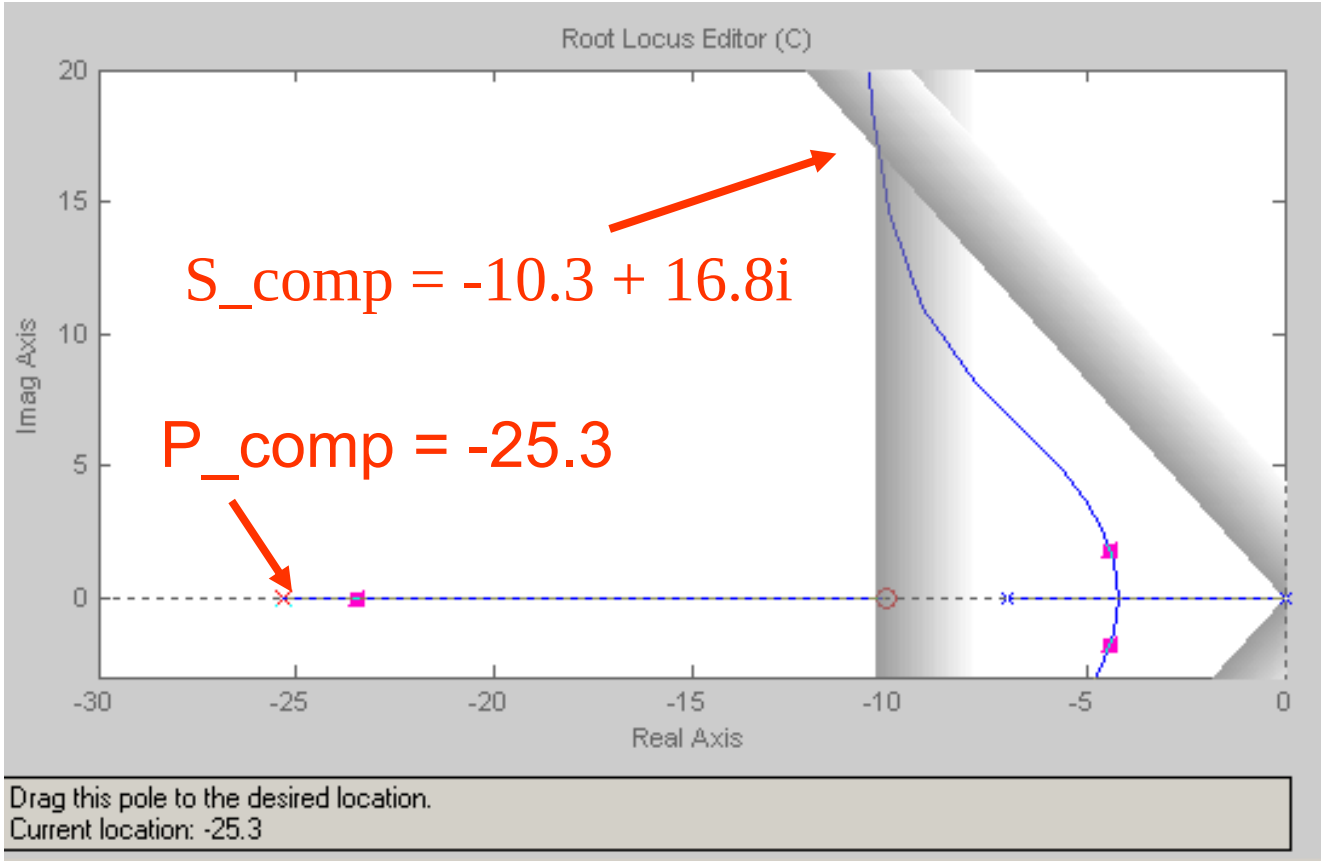




Exercício 2 – Resposta

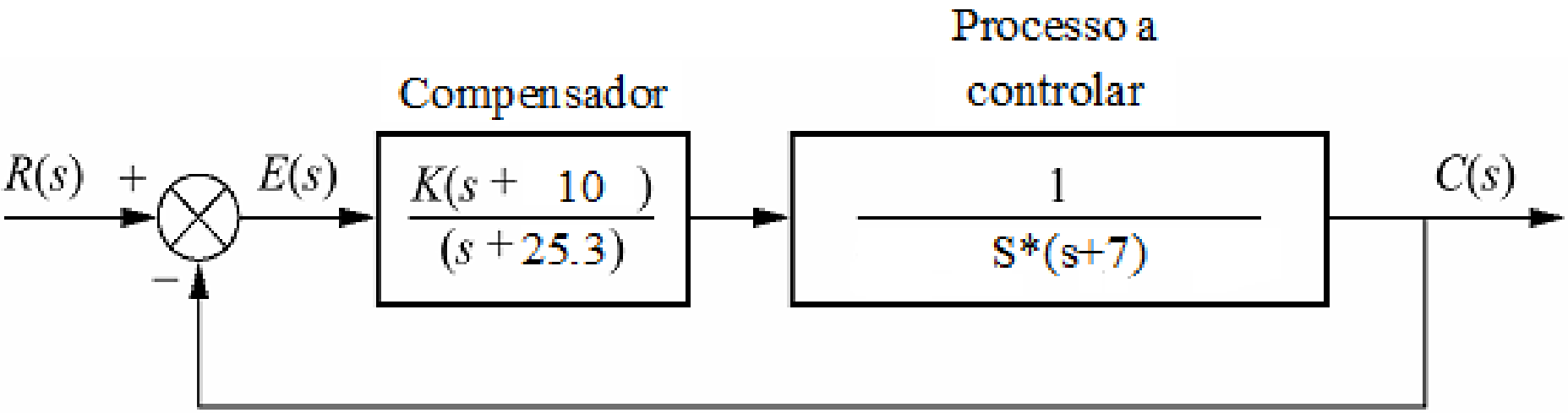
Sistema compensado





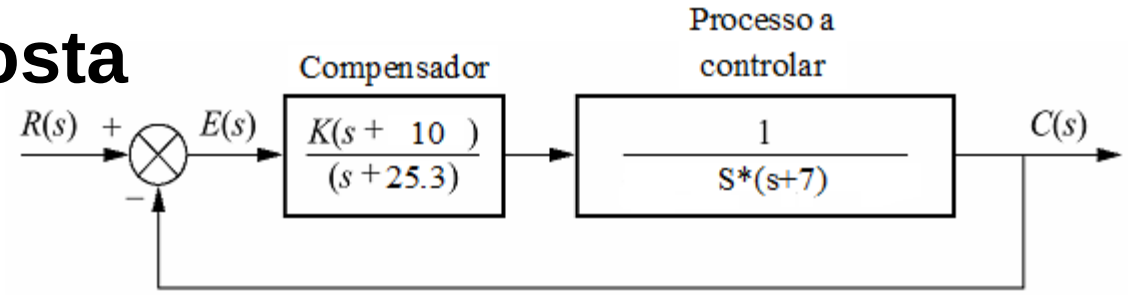
Exercício 2 – Resposta

Sistema compensado



Exercício 2 – Resposta

Sistema compensado



Condição de pertencer ao Root Locus

$$|G(s)| = 1 \longrightarrow K = 452.22$$

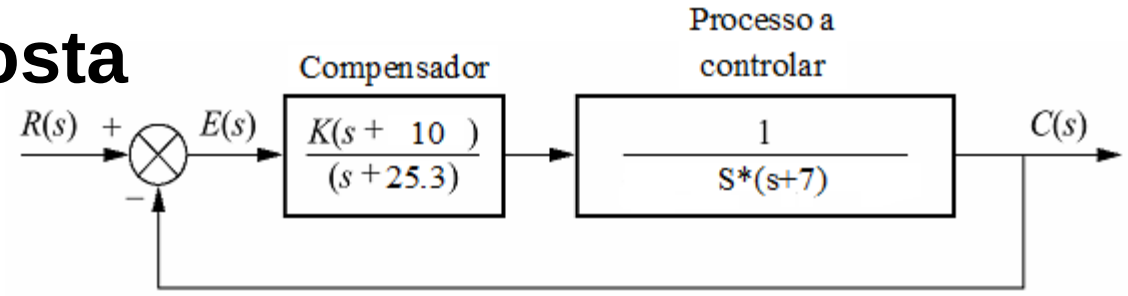
s = s2 = -10.3 + 16.8i

```
>> s2 = -10.3 + 16.8i

>> k_comp = abs(s2*(s2+7)*(s2+25.3)/(s2+10))
```

K_comp = 452.22

Exercício 2 – Resposta

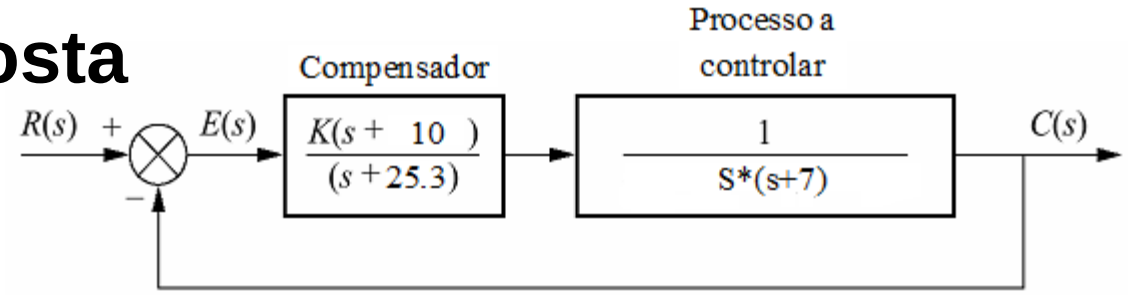


Sistema compensado

Resposta ao degrau:

```
>> gs = 46.23/(s*(s+7));
>> sys = feedback(gs,1);
>> step(sys)
>> hold on
>> gs_comp = (452.22*(s+10))/(s*(s+7)*(s+25.3));
>> sys_comp = feedback(gs_comp,1);
>> step(sys_comp)
>> legend('Original','Compensado')
```

Exercício 2 – Resposta



Sistema compensado

Resposta ao degrau: