Controle de Sistemas Dinâmicos

CSD – Exercícios Cap9
Projetos de Controle no LGR

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(Material de aula *Complementar*)

o projeto do controlador

é feito em função do **polo dominante**

-> todas as restrições devem ser atendidas

assumindo-se um sistema “ideal” de 2ª ordem sem zeros.

O projeto de sistemas “reais” não será “**exato**”.

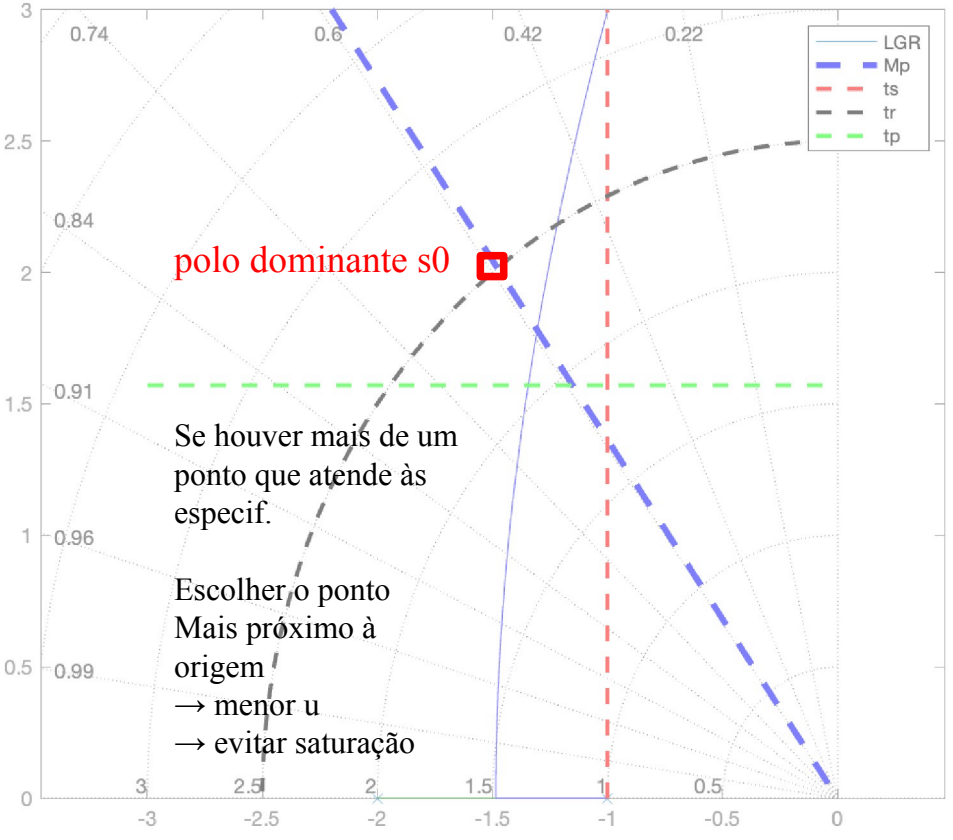
Algumas especificações

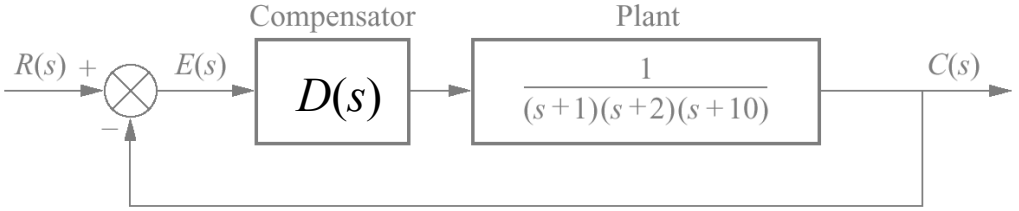
- **não completamente atendidas,**
- **outras sobre-atendidas!!**

```
zeta = -log(Mp/100)/sqrt(pi*pi+log(Mp/100)^2)
sigma=4/ts
wn=1.8/tr
wd=pi/tp

i=pi/2+.01:0.01:pi-.01; x=wn*cos(i);y=wn*sin(i);
plot(x,y,'k--','LineWidth',2);hold on;
plot([-sigma -sigma],[0 maxGr]*1,'r--','LineWidth',2);
plot([-maxGr 0],[wd wd],'g--','LineWidth',2);
plot([-maxGr 0]*1,[maxGr/tan(asin(zeta)) 0]*1,'b--','LineWidth',3)

title('Especifica\c{c}\~oes no plano s = $\sigma$ + $j\omega$ ', ...
      'fontsize',16,'interpreter','latex')
ylabel(' '),xlabel(' ')

axis([-maxGr 0 0 maxGr]); axis equal;
legend('LGR','tr','ts','tr','Mp')
```

especific_t2s(G,maxGr,Mp,ts,tr,tp) → .../CSD.html

```
g=zpk([],[-1 -2 -10],1)
especific_t2s(g,3,10,4,1.8/2.5,2)
```





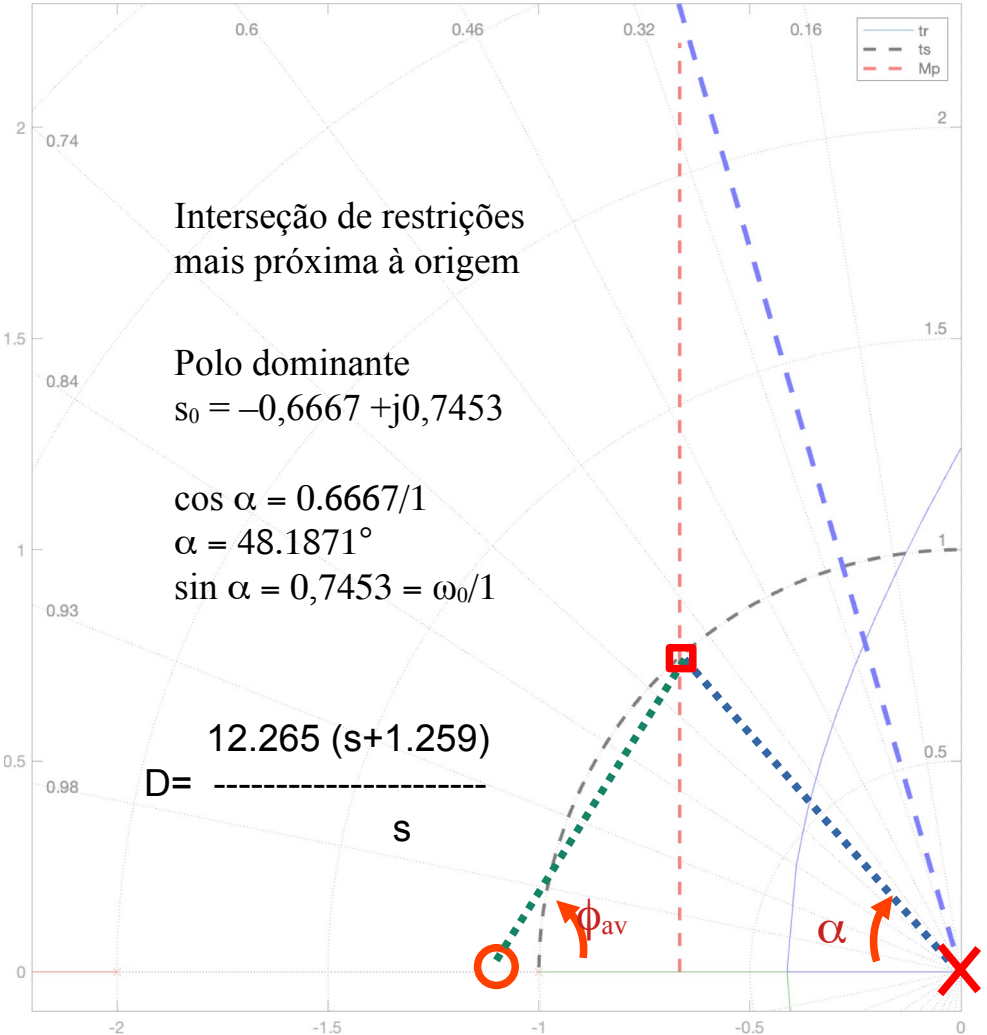
Especificações:
- $e_{ss} \leq 0.01$
- $t_s \leq 6$ s
- $M_p \leq 40\%$
- $t_r \leq 1.8$ s

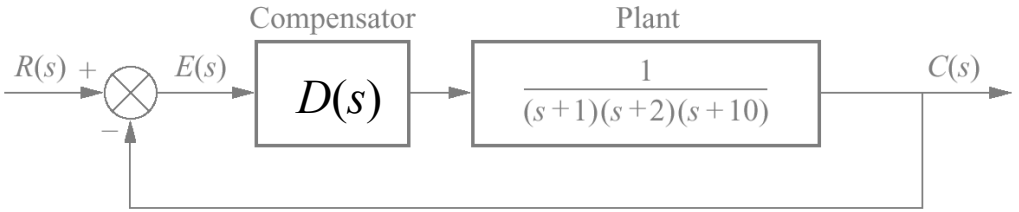
Canal I: $\phi_{av} = 180^o - /\underline{G(s)/s}_{s0}$
s=-.667+j*.7453; 180-angle(1/(s*(s+1)*(s+2)*(s+10)))*180/pi
$\phi_{av} = 51.52°$

$\tan \phi_{av} = .7453/\Delta \rightarrow \Delta = 0.5924 \Rightarrow z = -1.259$

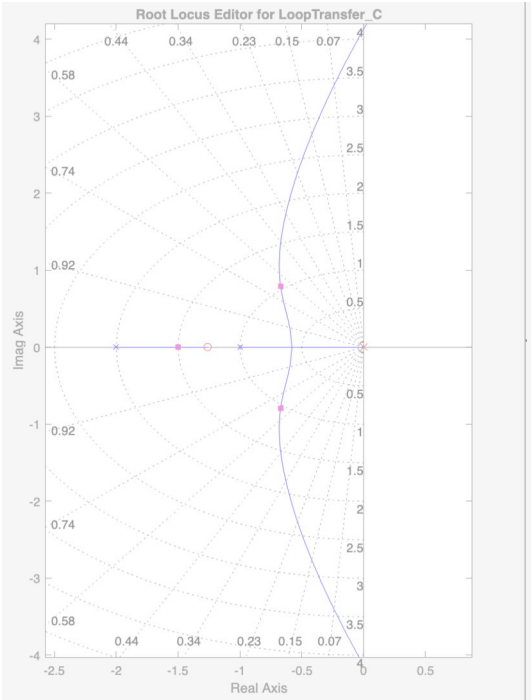
Condição | | → K|DG| = 1
s=-.667+j*.7453; abs((s*(s+1)*(s+2)*(s+10))/(s+1.259))
K = 12.2655

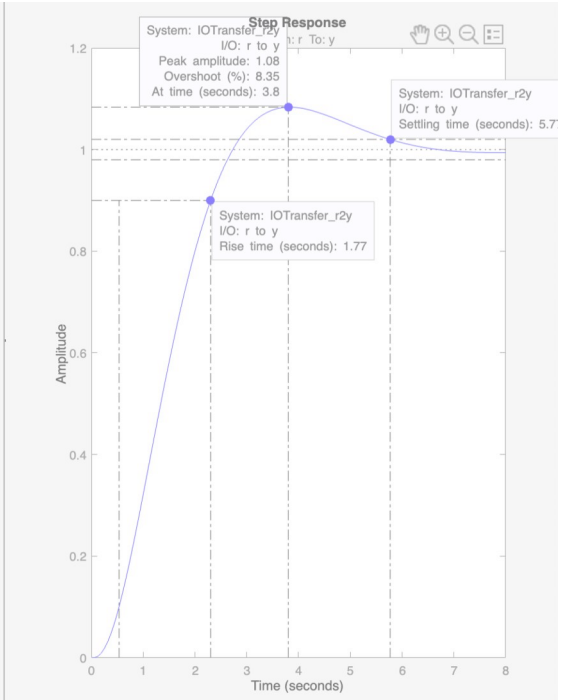
gs=zpk([],[0,-1 -2 -10],1); especific_t2s(gs, 2, 40, 6, 1.8)





Mp → sobre-atendido!





Especificações: especific_t2s(gs, 40, 6, 1.8)

- $e_{ss} \leq 0.01$
- $t_s \leq 6$ s
- $M_p \leq 40\%$
- $t_r \leq 1.8$ s

Interseção de restrições mais próxima à origem

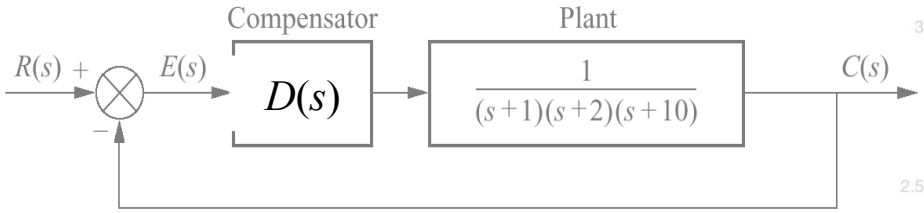
Polo dominante
$s_0 = -0{,}6667 + j0{,}7453$

$\cos \alpha = 0.6667/1$
$\alpha = 48.1871°$
$\sin \alpha = 0{,}7453 = \omega_0/1$

$$D = \frac{12.265\,(s+1.259)}{s}$$

ϕ_{av}

α



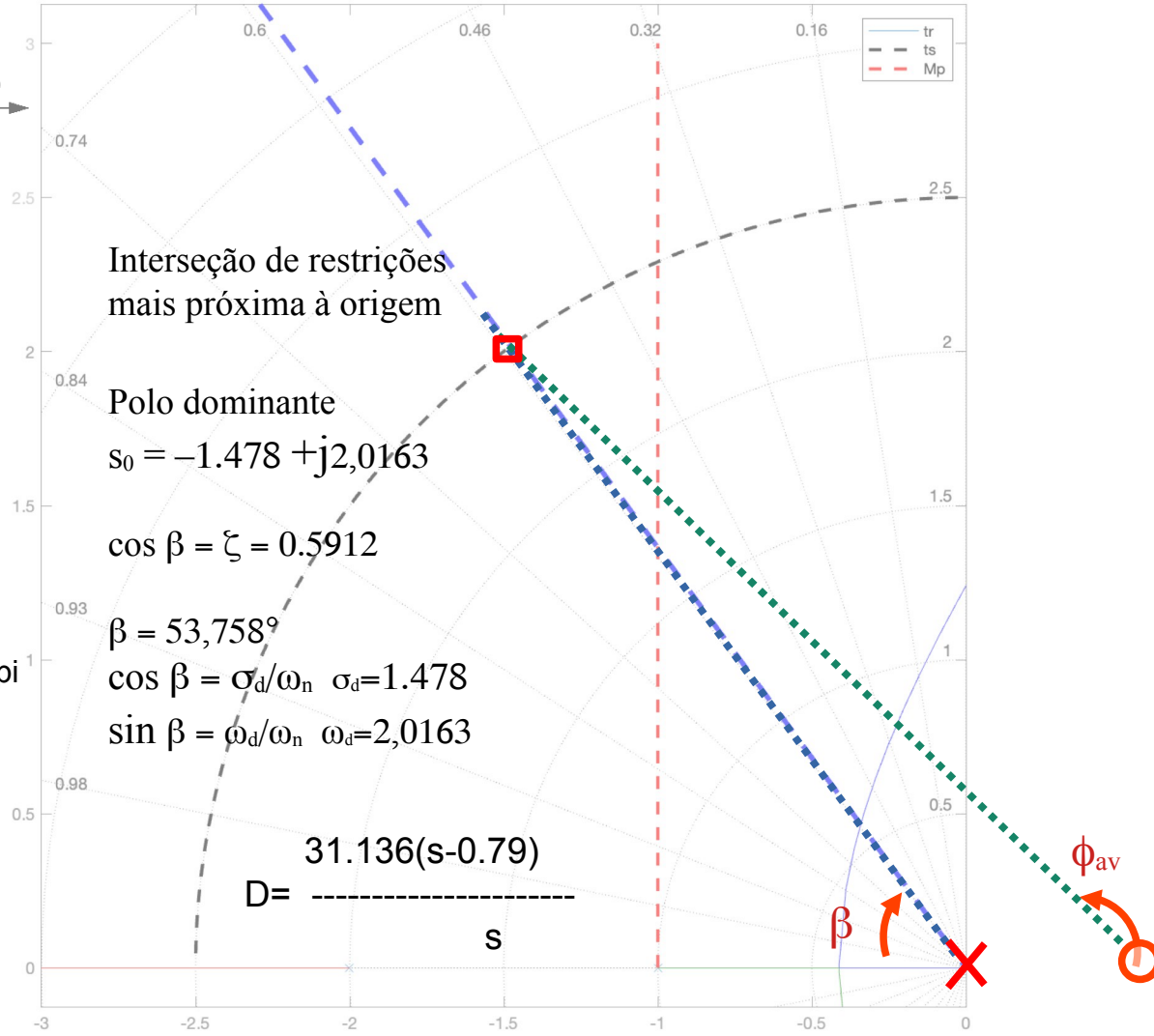
Especificações:
- $e_{ss} \leq 0.01$
- $t_s \leq 4$ s
- $M_p \leq 10\%$
- $t_r \leq 1.8/2.5$ s

Canal I: $\phi_{av} = 180° - \angle G(s)/s_{s0}$
s=–1.478 +j*2.0163; 180-angle(1/(s*(s+1)*(s+2)*(s+10)))*180/pi
Φ_{av} = 138.3759°

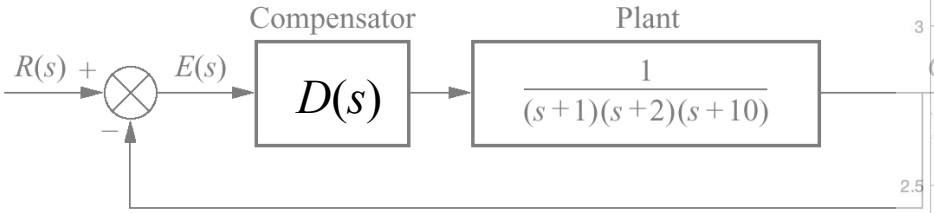
tan (180° - ϕ_{av})= 2.0163/Δ→Δ=2.2691 => z = -1.478 + 2.2691
z = 0,79 **(Semi-plano direito. Fase não-mínima!!)**

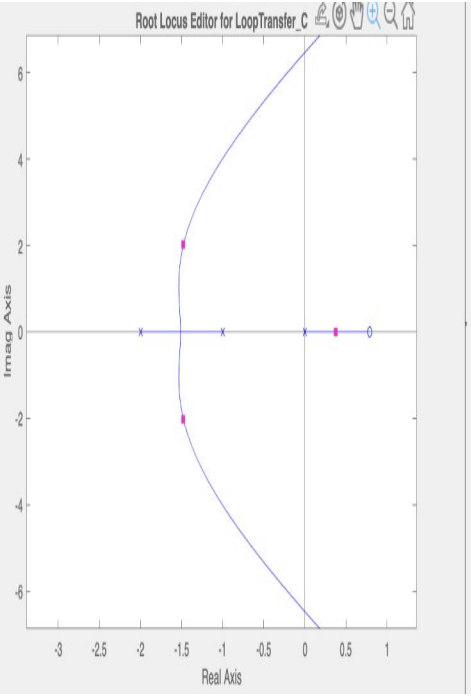
Condição | | → K|DG| = 1
s=–1.478 +j*2.0163; abs((s*(s+1)*(s+2)*(s+10))/(s-0.79))
K = 31.1362

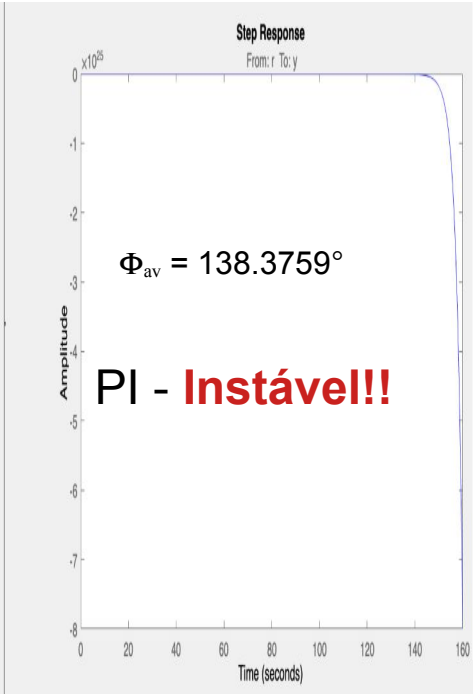
especific_t2s(gs, 3, 10, 4, 1.8/2.5)



especific_t2s(gs, 3, 10, 4, 1.8/2.5)

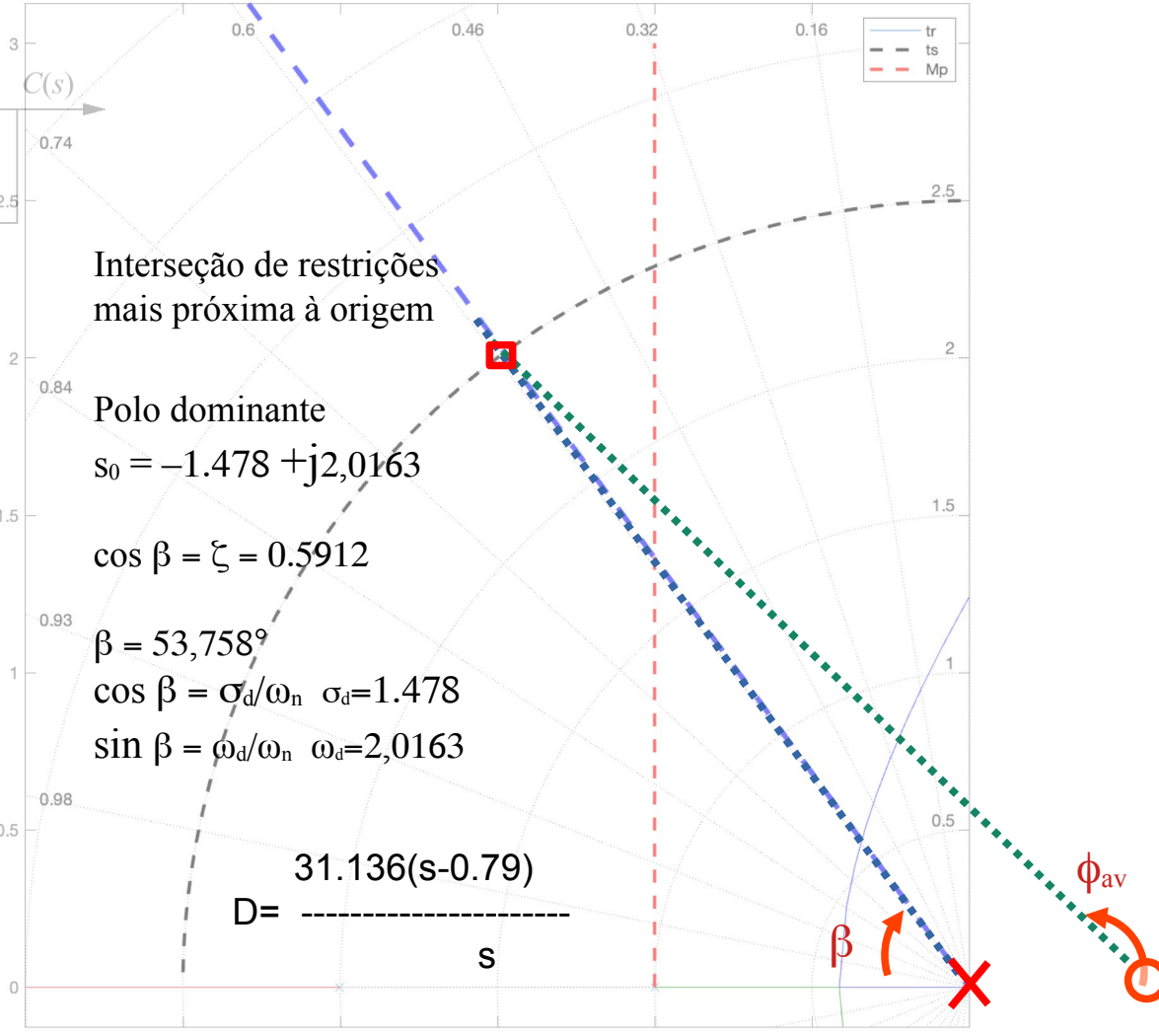






Φ_{av} = 138.3759°

PI - **Instável!!**



Interseção de restrições mais próxima à origem

Polo dominante

$s_0 = -1.478 + j2{,}0163$

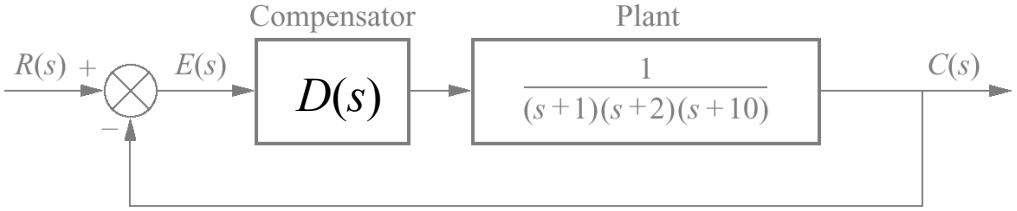
$\cos \beta = \zeta = 0.5912$

$\beta = 53{,}758°$

$\cos \beta = \sigma_d/\omega_n \quad \sigma_d = 1.478$

$\sin \beta = \omega_d/\omega_n \quad \omega_d = 2{,}0163$

$$D = \frac{31.136(s-0.79)}{s}$$



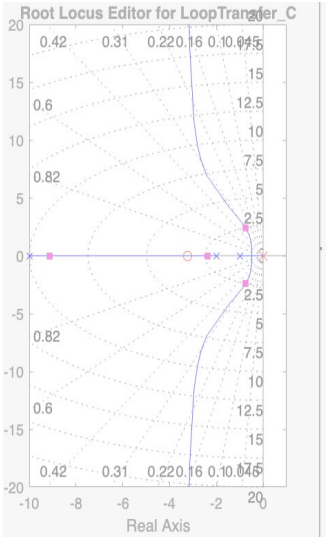
PID com zero duplo: $\Phi_{av}/2 = 69.188°$

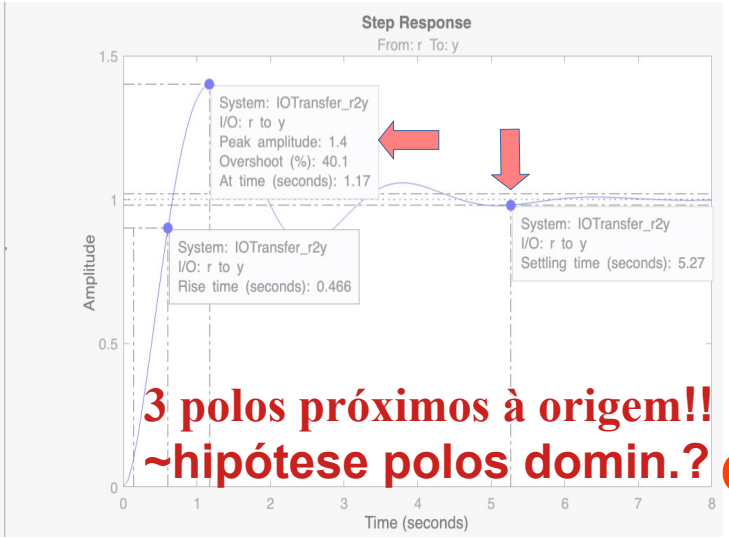
$\tan(180° - \phi_{av}/2) = 2.0163/\Delta \rightarrow \Delta = 1.7489 \Rightarrow z = -3.2269$

Condição $|\ | \rightarrow K|DG| = 1$

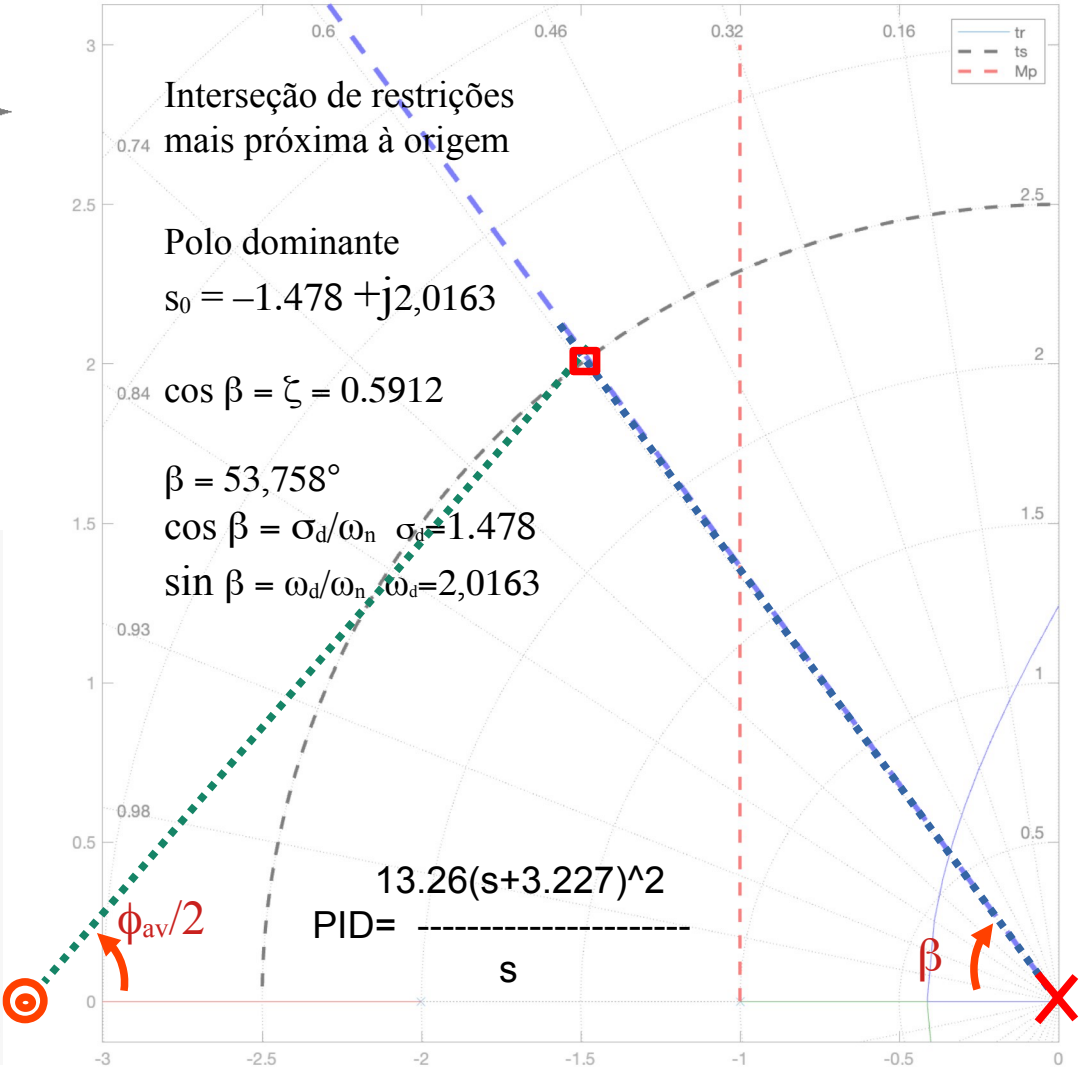
s=–1.478 +j*2.0163; abs((s*(s+1)*(s+2)*(s+10))/(s+3.2269)^2)

K = 13.2632





especific_t2s(gs, 3, 10, 4, 1.8/2.5)



PID cancelando polo em -2 (LGR leva polos em 0 e -1 p/ esquerda).

especific_t2s(gs, 3, 10, 4, 1.8/2.5)

$\phi_{av2} = 180° - \underline{/(s+2)G(s)/s}_{s0}$

s=–1.478 +j*2.0163; 180-angle(1/(s*(s+1)*(s+10)))*180/pi

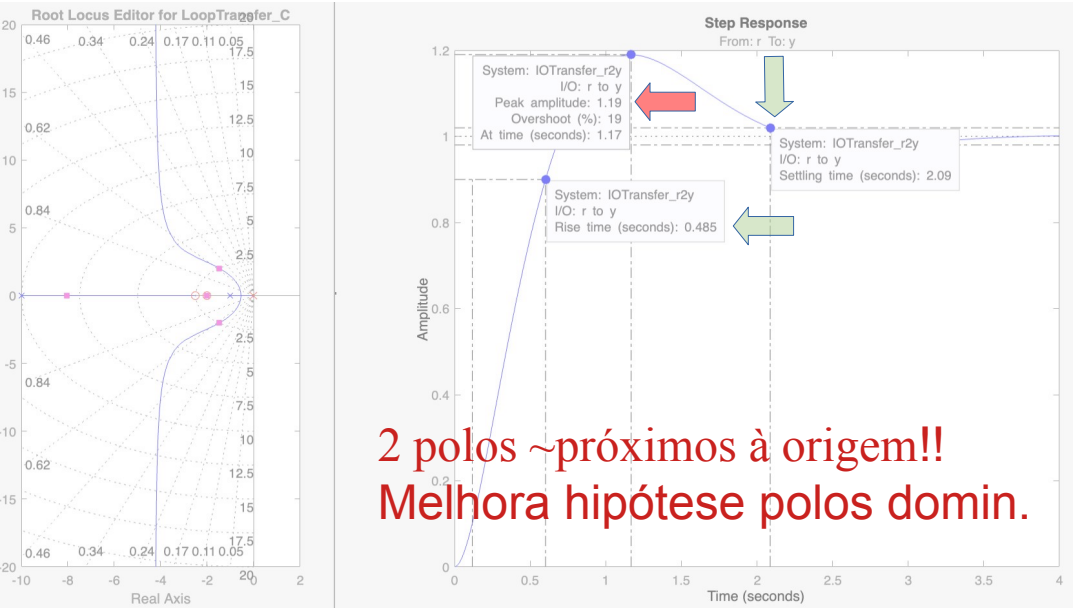
$\Phi_{av2} = 62.89°$

$\tan(\phi_{av2}) = 2.0163/\Delta \rightarrow \Delta = 1.0322 \Rightarrow z = -2.51$

Condição | | → K|DG| = 1

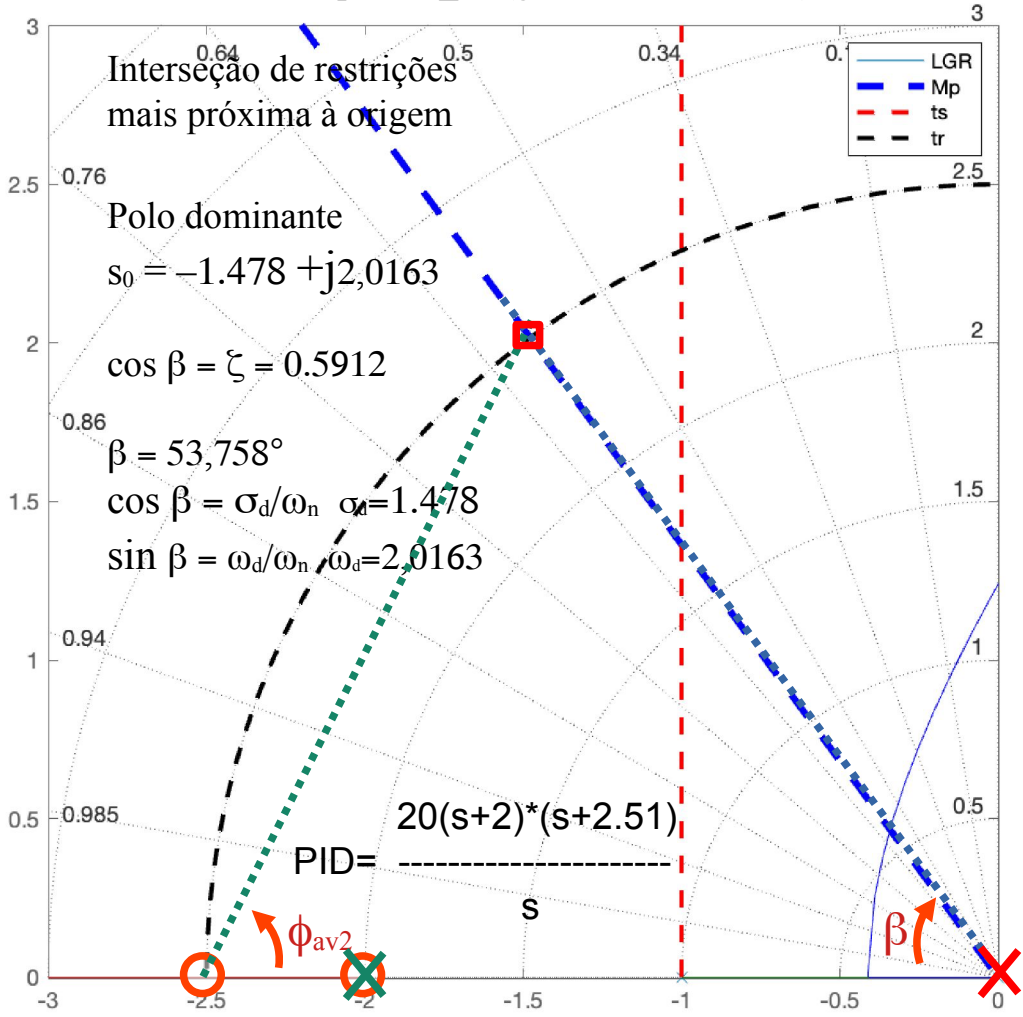
s=–1.478 +j*2.0163; abs((s*(s+1)*(s+10))/(s+2.51))

K = 20



2 polos ~próximos à origem!!

Melhora hipótese polos domin.



Compensador em Avanço: $\phi_{av} = 180^o - /\underline{G(s)}_{s0}$

s=–1.478 +j*2.0163; 180-angle(1/((s+1)*(s+2)*(s+10)))*180/pi

1. Compensador em Avanço: $\Phi_{av} = 12.1335°$

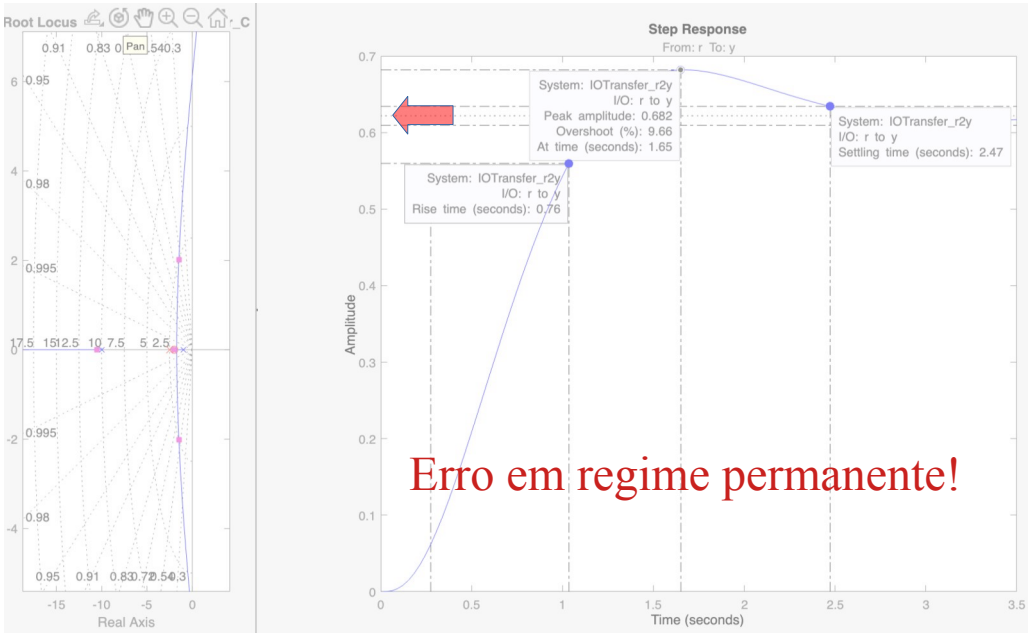
s=-1.478+j*2.0163, angle (s+2) – angle(s+z) = 12.1335°

angle(s+z) = angle (s+2) -12.1335° = 75.485–12.133= 63.352°

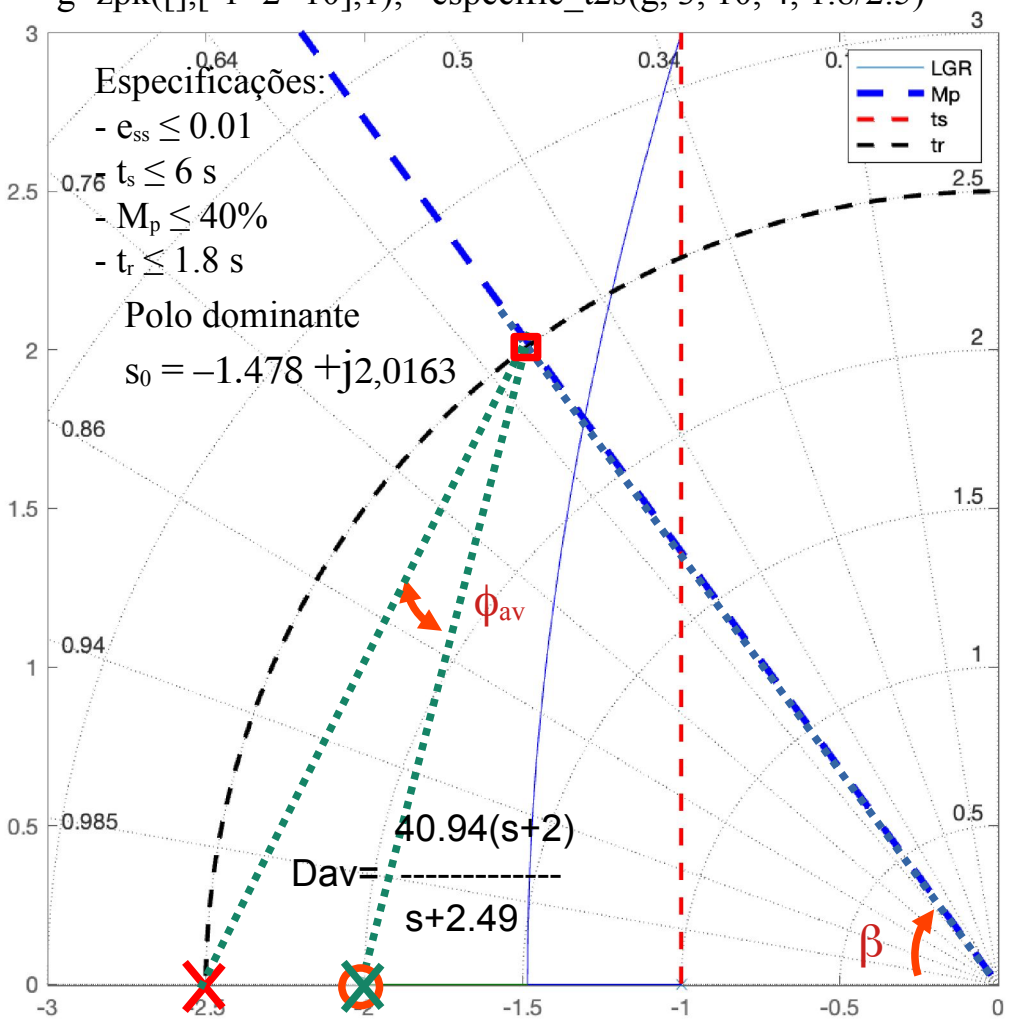
tan (ϕ_{av})= 2.0163/Δ→Δ=1.0118 => p = - 2.4898

Condição | | → K|DG| = 1

s=–1.478 +j*2.0163; abs(((s+1)*(s+10)*(s+2.49)), K = 40.94



g=zpk([],[-1 -2 -10],1); especific_t2s(g, 3, 10, 4, 1.8/2.5)



Compensador em Avanço: ***Método da Bissetriz***

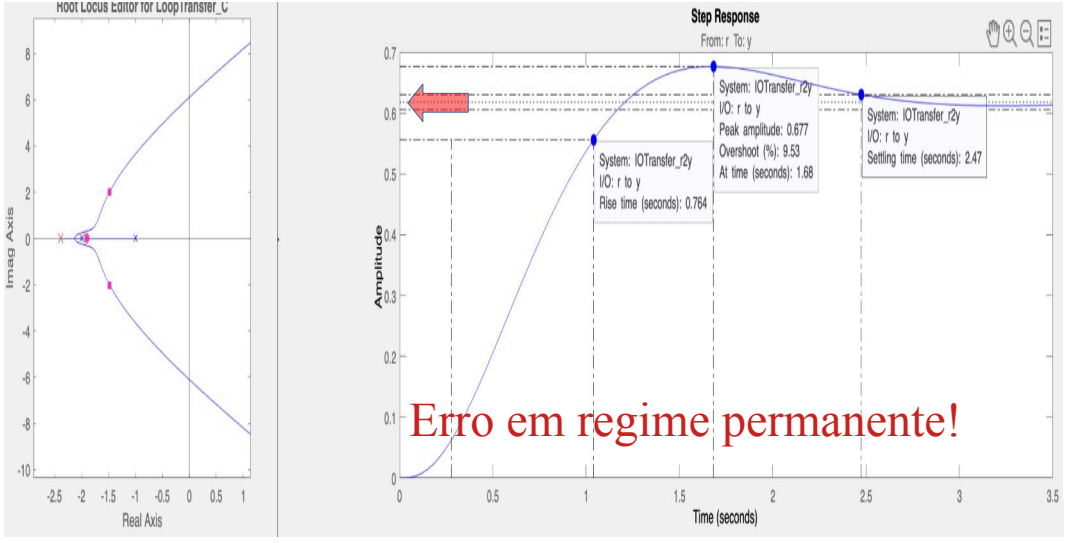
g=zpk([],[-1 -2 -10],1); especific_t2s(g, 3, 10, 4, 1.8/2.5)

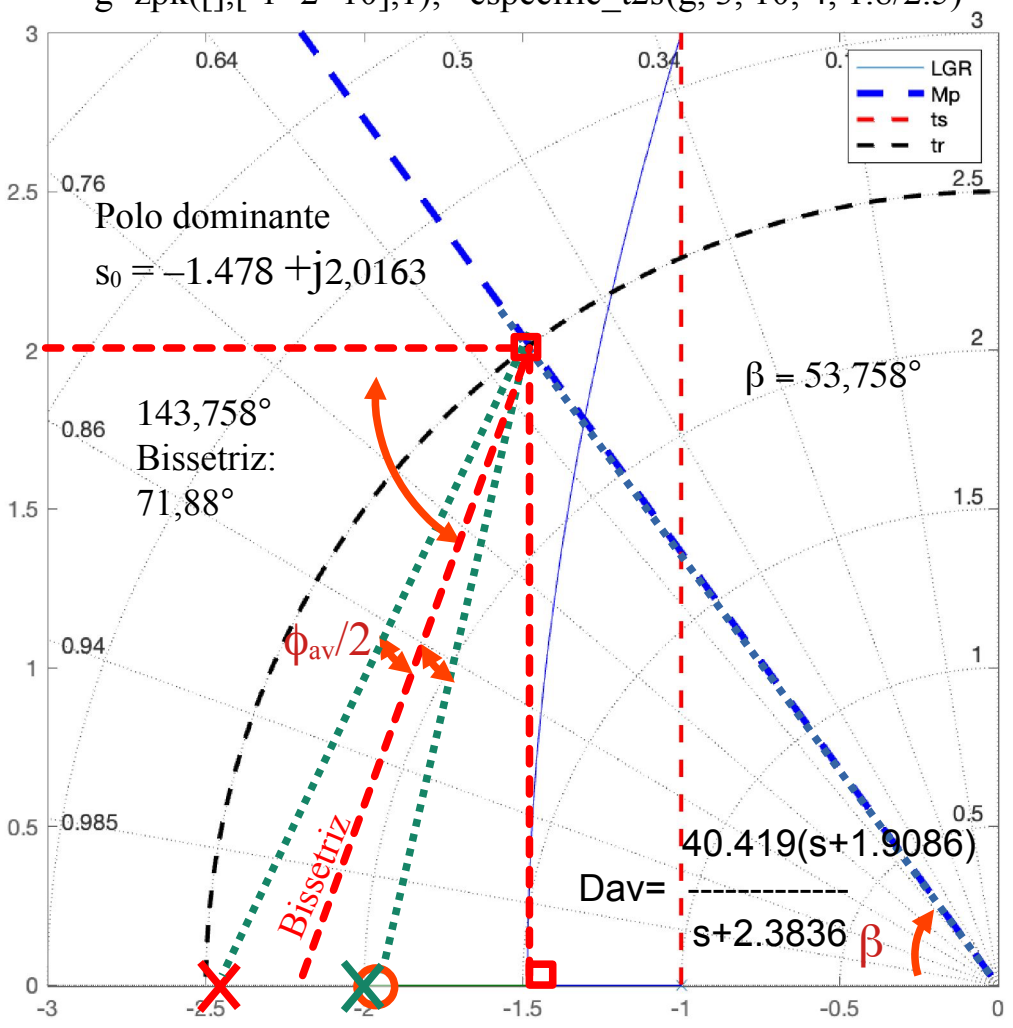
s=–1.478 +j*2.0163; 180-angle(1/((s+1)*(s+2)*(s+10)))*180/pi
Φ_{av} = 12.1335°

s=-1.478+j*2.0163, angle (s+2) – angle(s+z) = 12.1335°

71.88 ±12.1335° = 77.9458° / 65.8123°.
Tand(90-77.9458)*2.0163 +1.478 = 1.9086 = z
Tand(90-65.8123)*2.0163 +1.478 = 2.3836 = p

Condição | | → K|DG| = 1
s=–1.478 +j*2.0163;
abs(((s+1)*(s+2)*(s+10)*(s+2.3836)/(s+1.9086))), K = 40.419





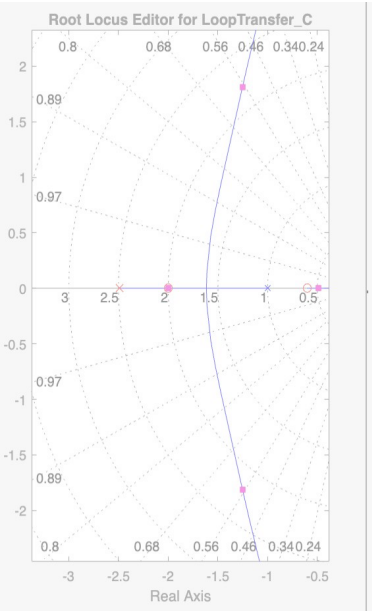
2. Compensador em Avanço-Atraso: (acrescentando atraso).

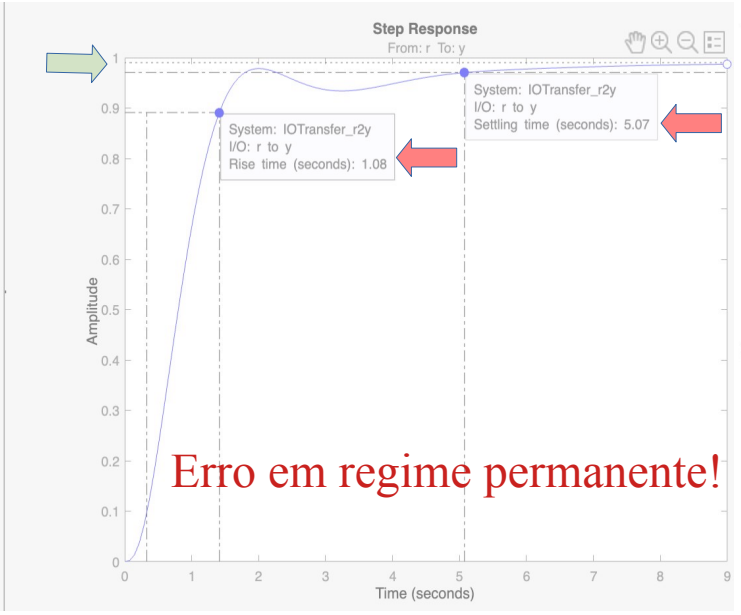
Condição | | → K|DG| = 1
s=–1.478 +j*2.0163;
40.94/((s+1)*(s+10)*(s+2.49)), K_p = lim s 1/s () = 1.6442 => e_{ss} = 0,3782

1/(1+Kp') = 0.01 → Kp' = 99 Kat = 99/1.6442 = 60.2117

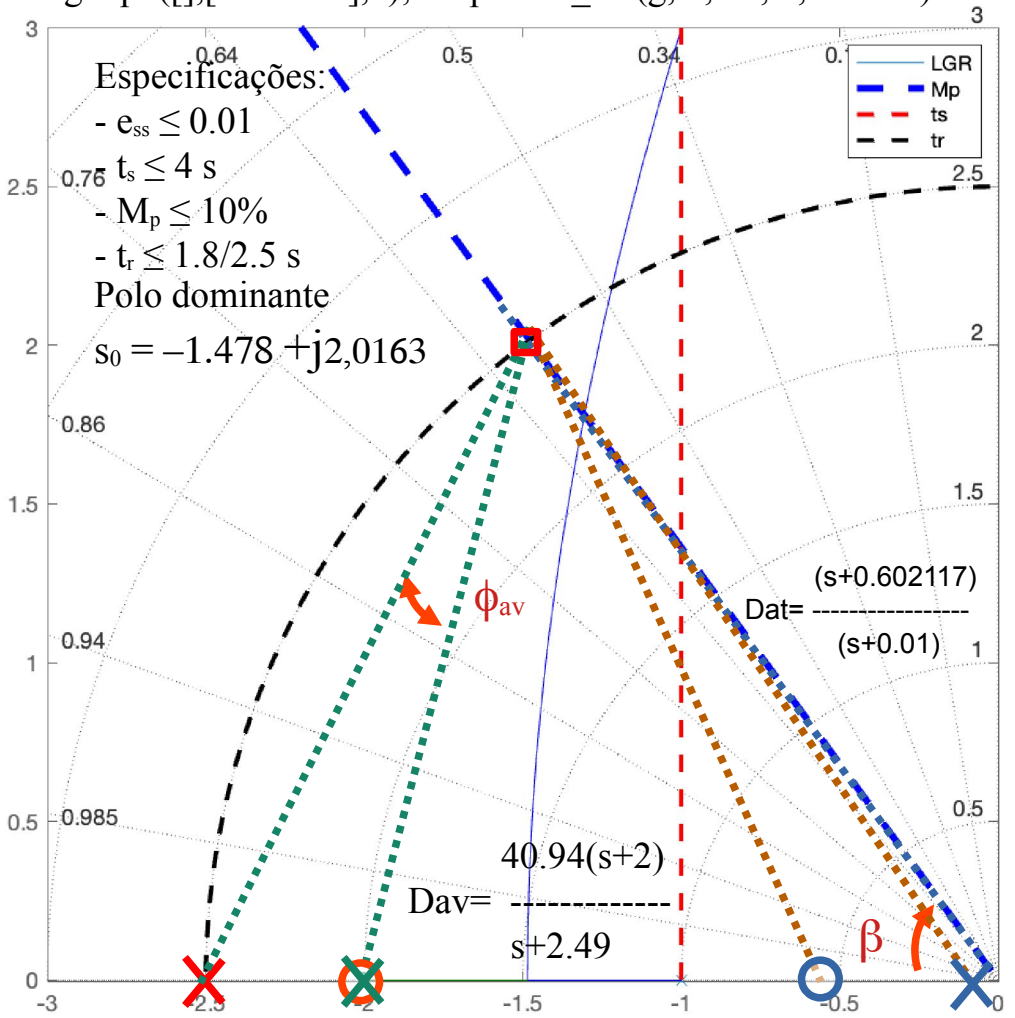
→ Dat=(s+0.602117)/(s+0.01)

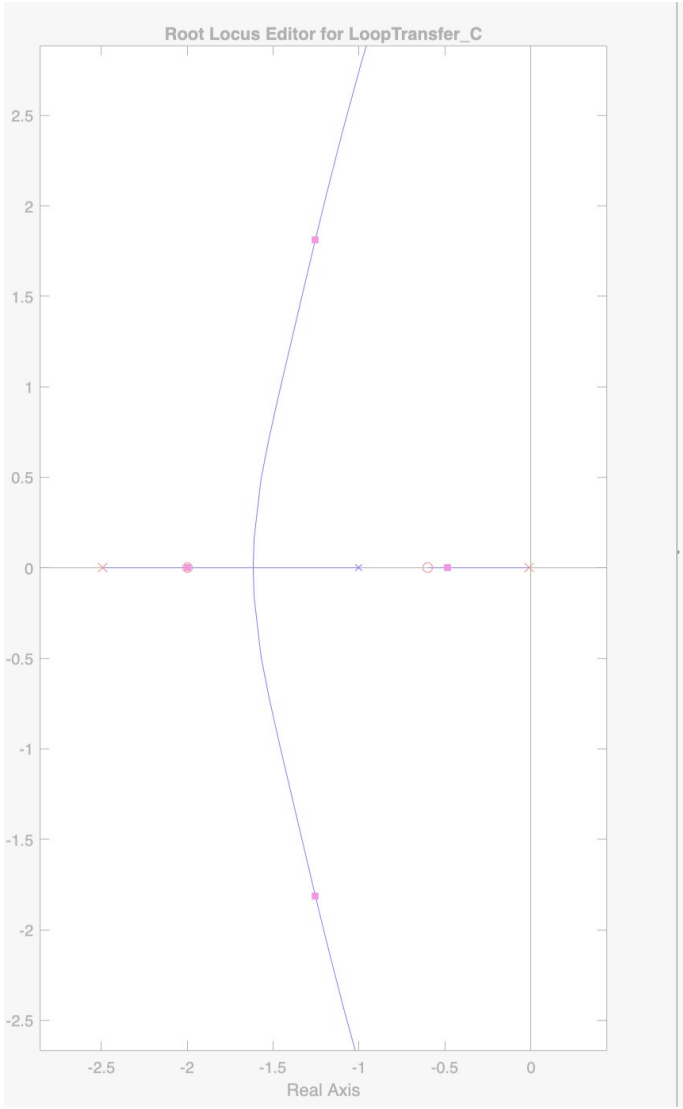
g=zpk([],[-1 -2 -10],1); especific_t2s(g, 3, 10, 4, 1.8/2.5)

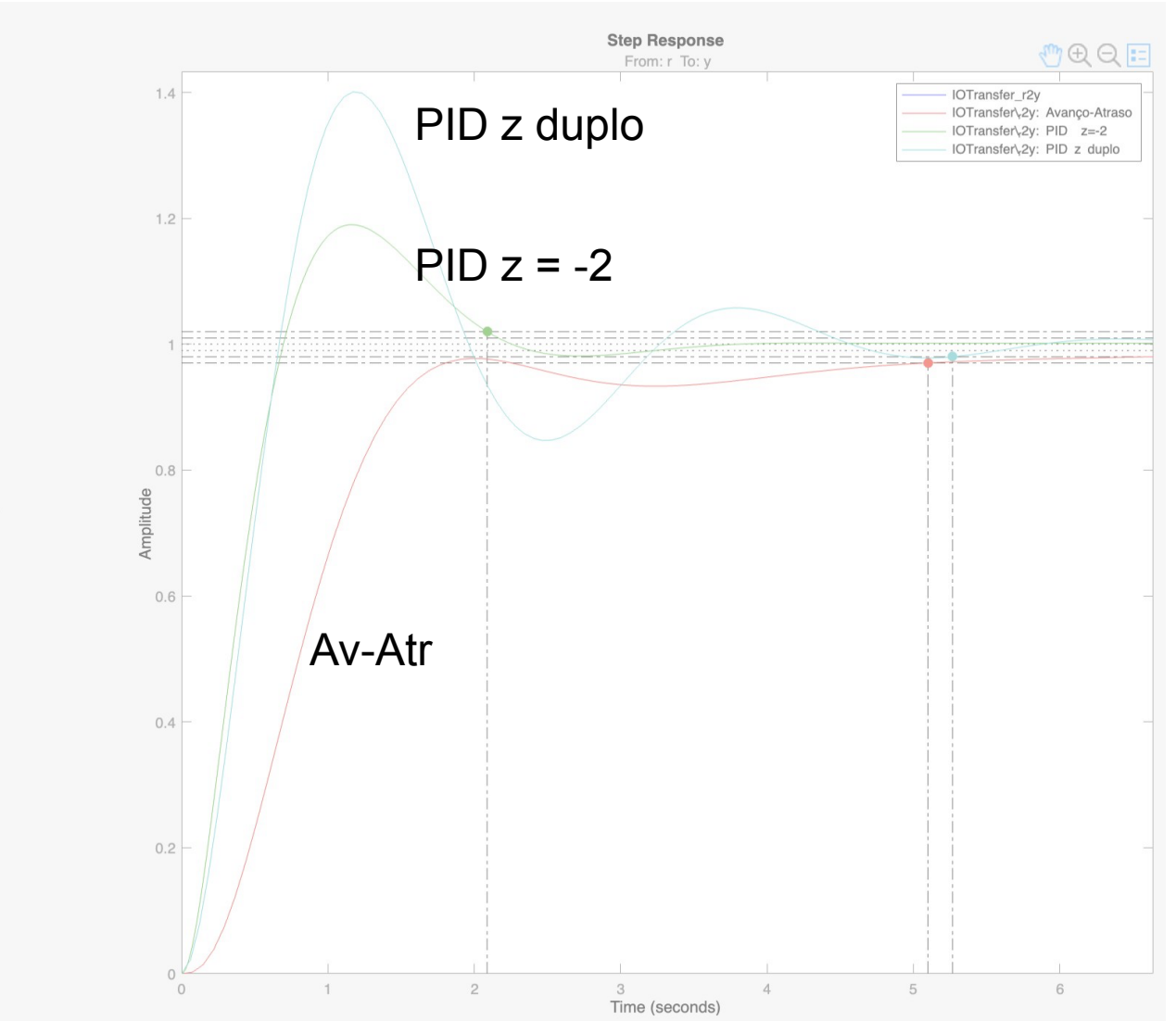




Erro em regime permanente!




Root Locus Editor for LoopTransfer_C
Real Axis

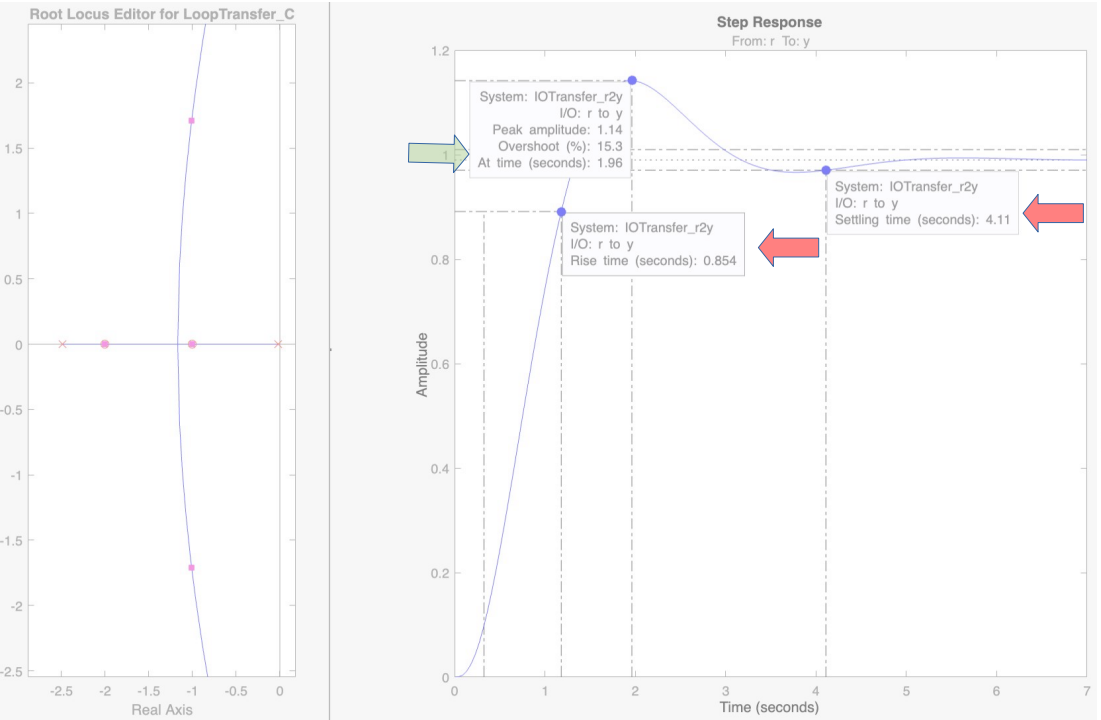

Step Response
From: r To: y
IOTransfer_r2y
IOTransfer\,2y: Avanço-Atraso
IOTransfer\,2y: PID z=-2
IOTransfer\,2y: PID z duplo
PID z duplo
PID z = -2
Av-Atr
Amplitude
Time (seconds)

2. Compensador em Avanço-Atraso: (cancelando polo em -1).

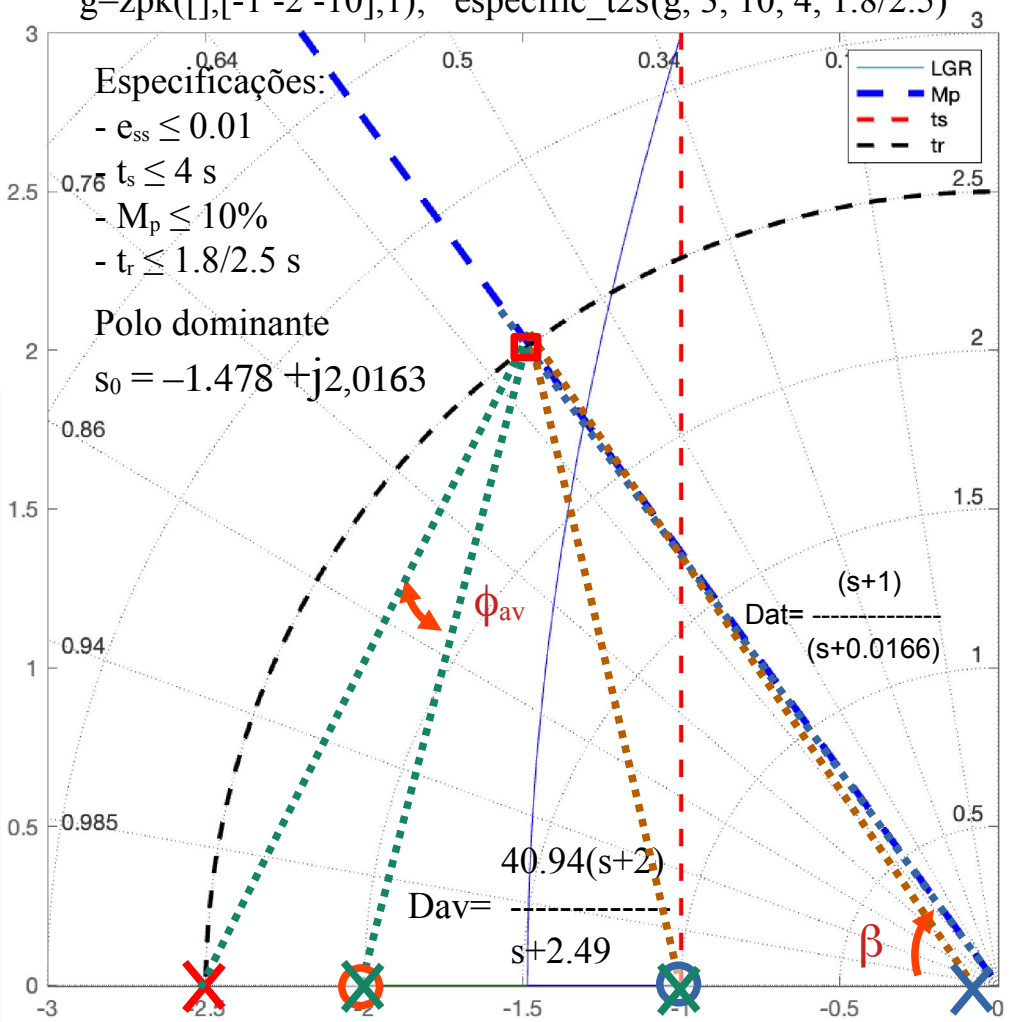
Condição | | → K|DG| = 1
s=–1.478 +j*2.0163;
40.94/((s+1)*(s+10)*(s+2.49)), K_p = lim s 1/s () = 1.6442 => e_{ss} = 0,3782

1/(1+Kp') = 0.01 → Kp' = 99 Kat = 99/1.6442 = 60.2117

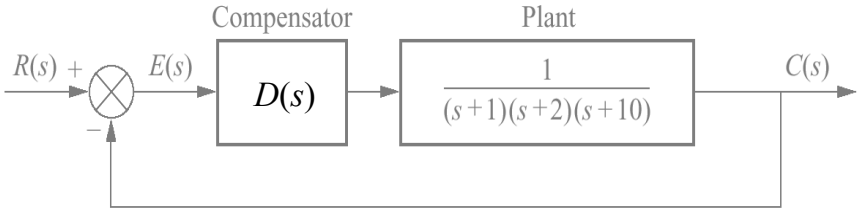
→ Dat=(s+1)/(s+0.0166)



g=zpk([],[-1 -2 -10],1); especific_t2s(g, 3, 10, 4, 1.8/2.5)



Especificações: e_{ss}=0.01, Mp=10%, t_s=4s, t_r=0.72



PID: e_{ss}=0.0, Mp=19%, t_s=2s, t_r=0.485

Av-Atr: e_{ss}=0.01, Mp=15,3%, t_s=4,11s, t_r=0.854