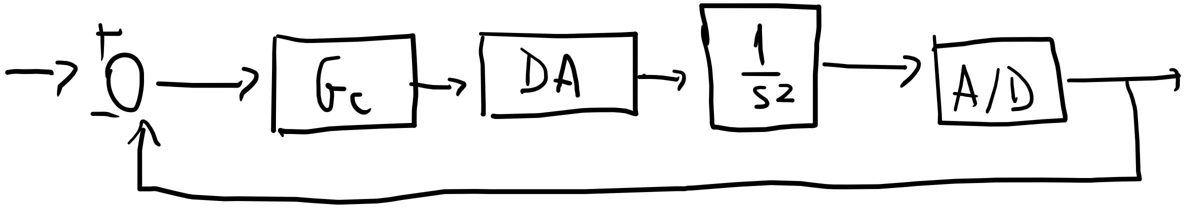
Escola Politécnica da Universidade de São Paulo
Departamento de Engenharia Mecatrônica e de Sistemas Mecânicos - PMR

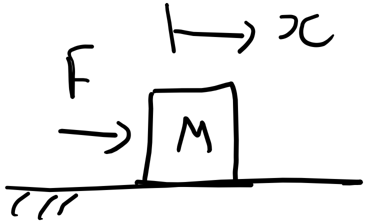
Aula 10

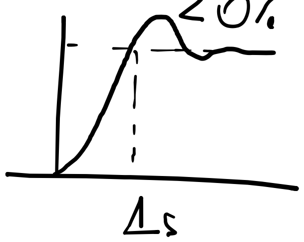
Projeto de Controle – Exemplo Projeto Indireto

Prof. Eduardo A. Tannuri

PMR 3409 – Controle II







ESPECIF. $M_p = 20\%$

$t_r = 1s$

POLOS DESEJADOS

$$t_r = \frac{\pi - \beta}{w_d}$$

$$\beta = \arccos \zeta$$

$$M_p = \exp\left(\frac{-\pi \zeta}{\sqrt{1-\zeta^2}}\right)$$

$\Rightarrow$

```
#especificacao de controle
Mp  = 0.2
tr = 1

#polos desejados
zeta = np.sqrt(np.log(Mp)**2 / (np.log(Mp)**2 + np.pi**2))
beta = np.arccos(zeta)
wd = (np.pi - beta)/tr
wn = wd / np.sqrt(1-zeta**2)
sdes = wn*(-zeta +np.sqrt(1-zeta**2)*1j)
```

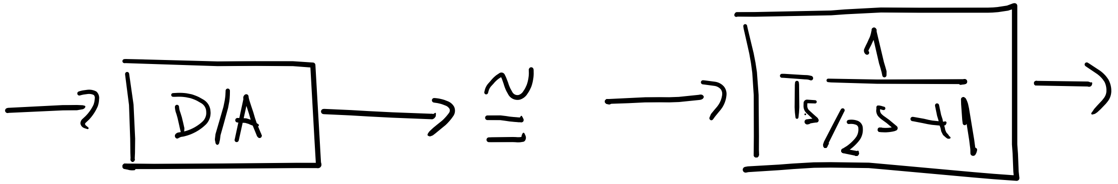
$S_{1,2} \approx -1 \pm 2j$

tempo Amostragem

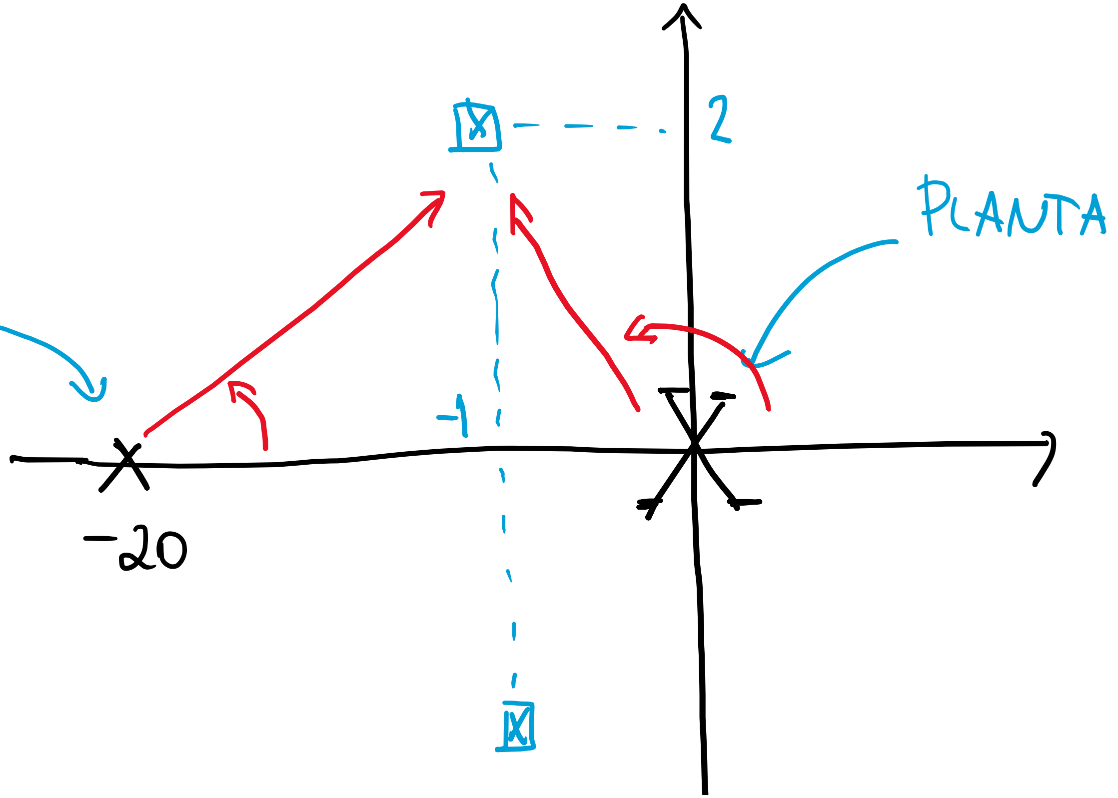
$$T_s = \frac{2\pi}{\omega_d} \cdot \frac{1}{30} \;\mapsto \text{bom}$$

$30 \; \nu \cong 5; 20; 30$

$$\boxed{T_s = 0{,}1\ s}$$



$$\frac{1}{0{,}05s + 1}$$

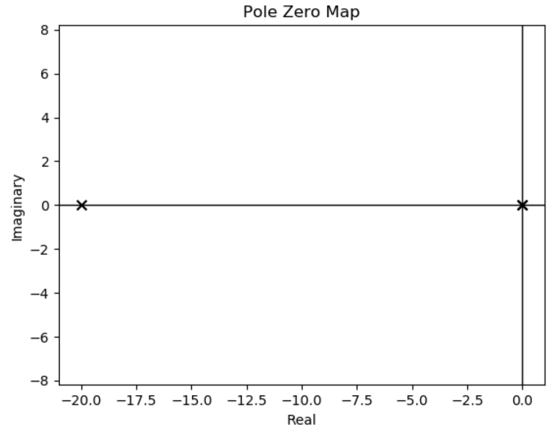


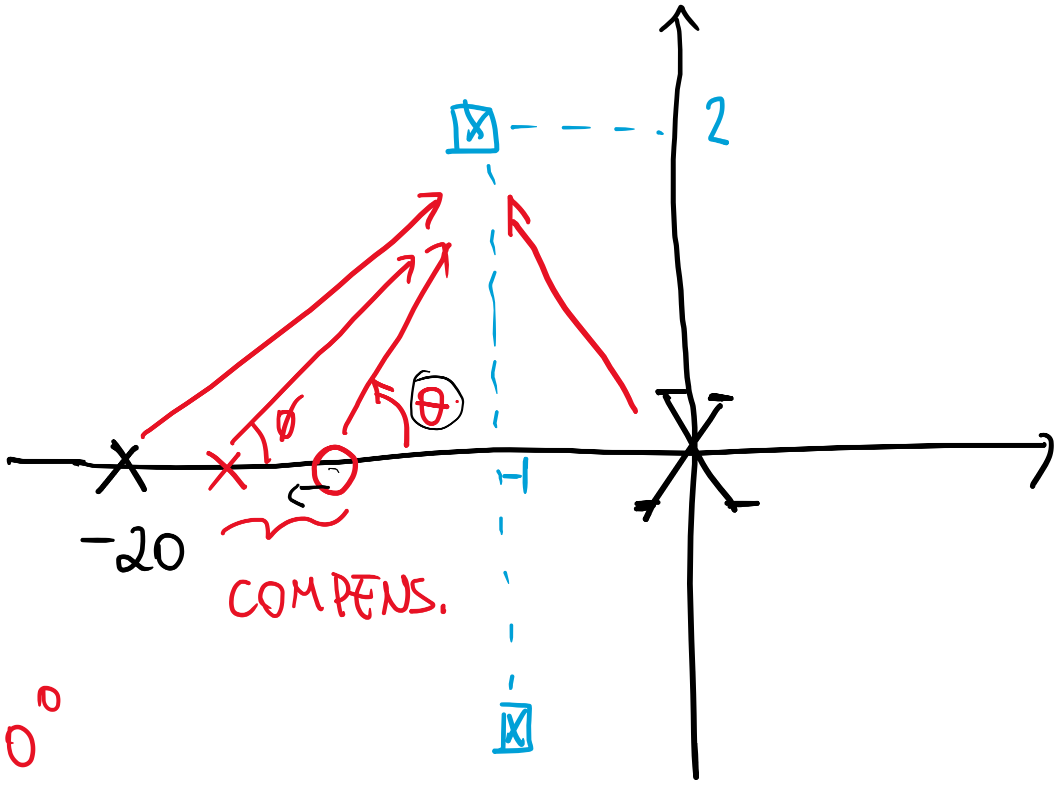
CONDIÇÃO FASE

```
#ZOH e planta
Gzoh = tf(1,[Ts/2,1])
G = tf(1,[1,0,0])
pzmap(G*Gzoh)

#condicao de fase
p = pole(Gzoh)
fase_atual =(cm.phase(sdes-p[0])+2*cm.phase(sdes-0))*-180/np.pi
avanco = -180 - fase_atual
```

→ -240°

$= 60^\circ$

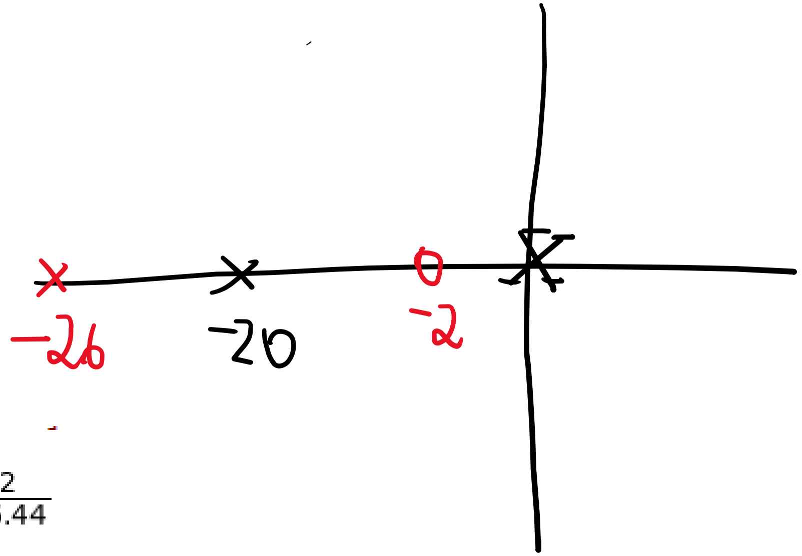




$\theta - \phi = 60^\circ$

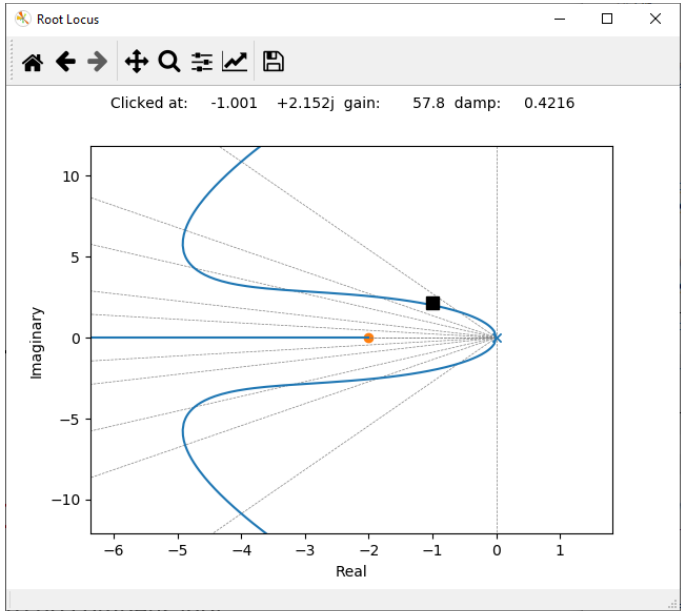
```
#definir polo e zero do compensador
zc = -2.0
fase_polo = avanco - cm.phase(sdes-zc)*180/np.pi
pc = sdes.real - sdes.imag / np.tan(-fase_polo*np.pi/180)

Gc = tf([1,-zc],[1,-pc])
```

$$\frac{s+2}{s+26.44}$$



CALCULAR GANHO)

1) POR RLOCUS



2) POR COND. MÓDULO

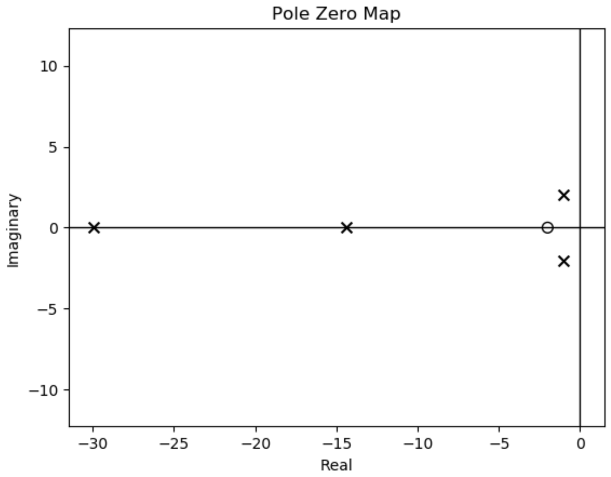
$$\left| G_c(s) \cdot G(s) \cdot G_{ZOH}(s) \right|_{s=s_{des}} = 1$$

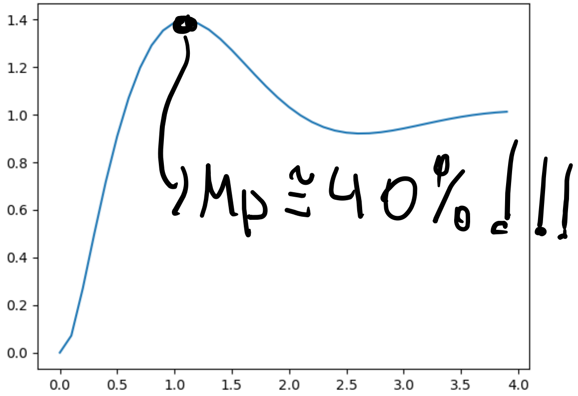
$$\boxed{K = 56{,}7}$$

```
# condição de módulo
K = 1/abs(evalfr(Gc*G*Gzoh,sdes))
Gc = K * Gc
```

VERIFICAR PROJETO EMS

Eigenvalue		Damping	Frequency
-29.98		1	29.98
-14.36		1	14.36
-1.047	+2.044j	0.4559	2.297
-1.047	-2.044j	0.4559	2.297



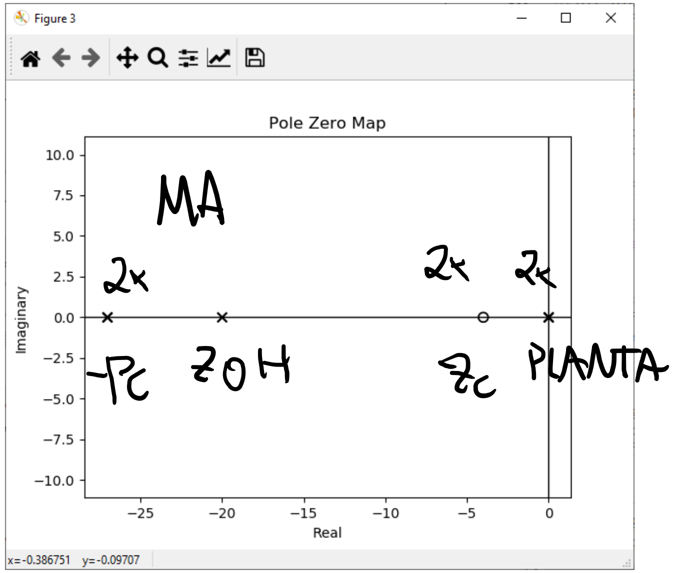


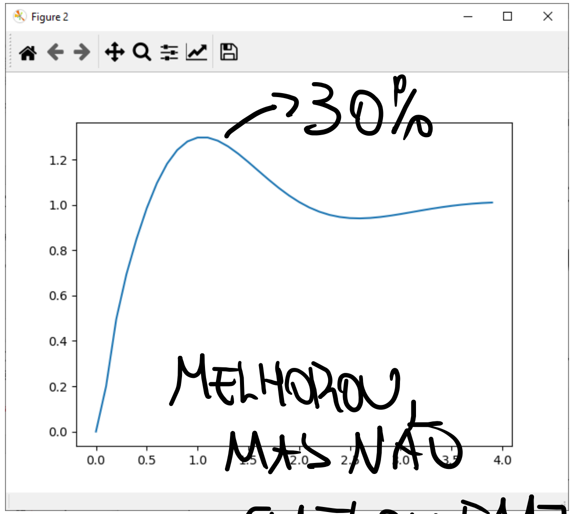
- O ZERO EM MF DEGRADOU MUITA RESPOSTA

- VAMOS TENTAR 2 COMPENSADORES AVANÇO EM SÉRIE

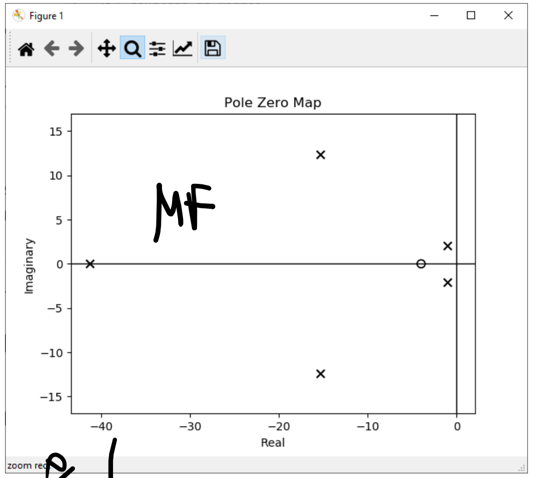
```
#definir polo e zero do duplo compensador
avanco2 = avanco / 2
zc = -4
fase_polo = avanco2 - cm.phase(sdes-zc)*180/np.pi
pc = sdes.real - sdes.imag / np.tan(-fase_polo*np.pi/180)

Gc = tf([1,-zc],[1,-pc]) * tf([1,-zc],[1,-pc])

# condição de módulo
K = 1/abs(evalfr(Gc*G*Gzoh,sdes))
Gc = K * Gc
```

$$G_c(s) = K \cdot \left(\frac{s+z_c}{s+p_c}\right)^2$$



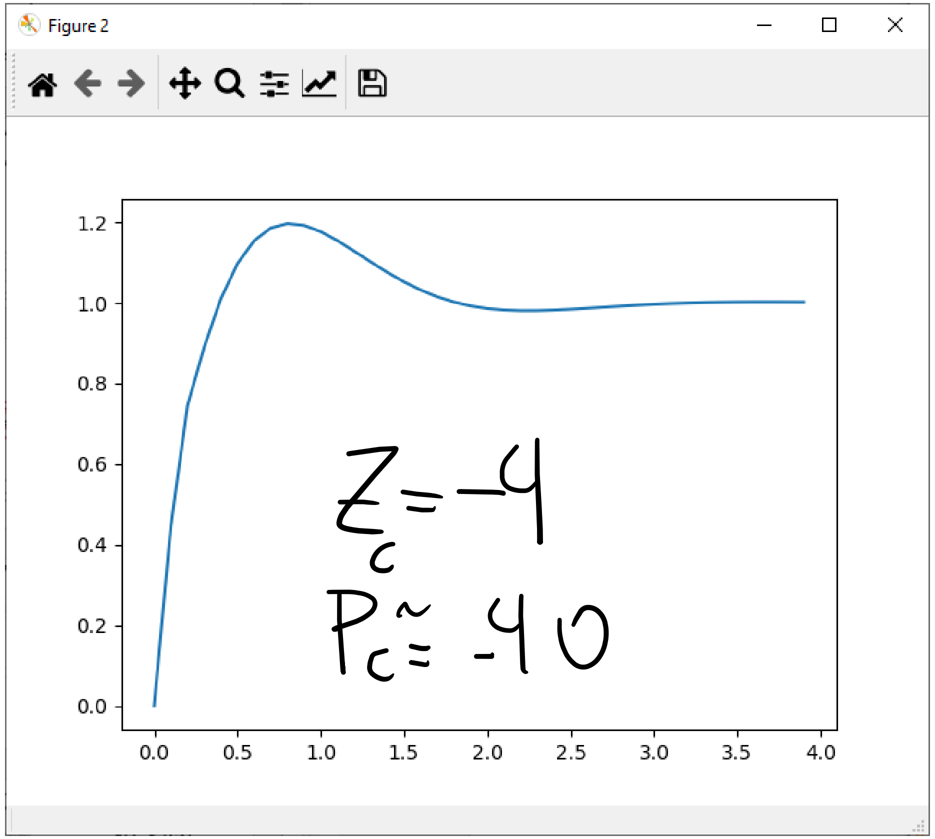


MELHOROU, MAS NÃO CHEGOU EM 20%!



- TESTAMOS P/ OUTROS Z_c E NÃO MELHOROU

- ALTERNATIVA → $M_p = 10\%$



UFA! ATENDE REQUISITOS NO CONTÍNUO

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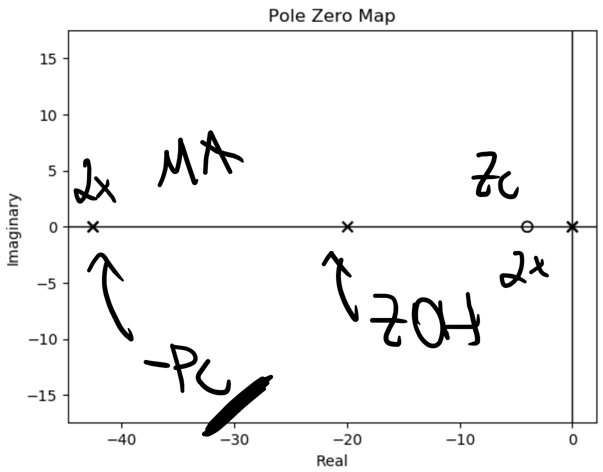
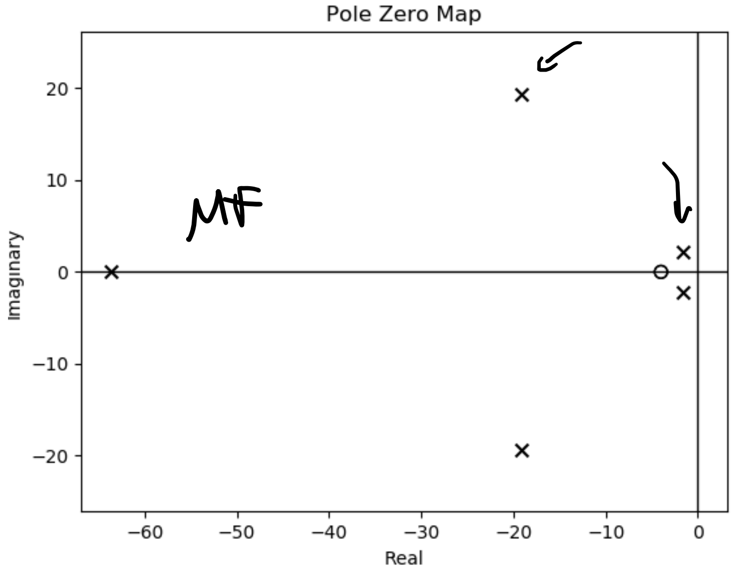
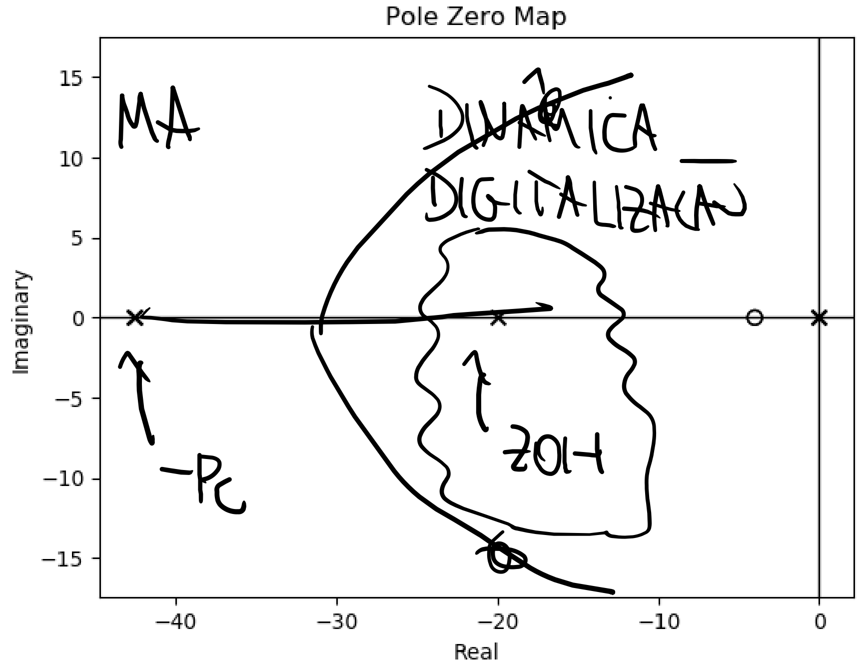
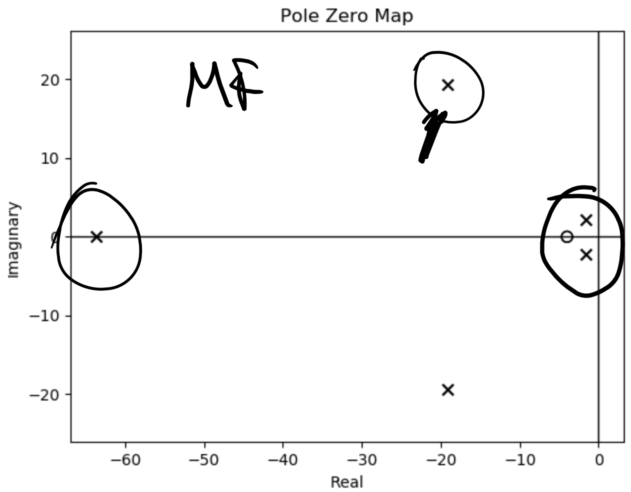
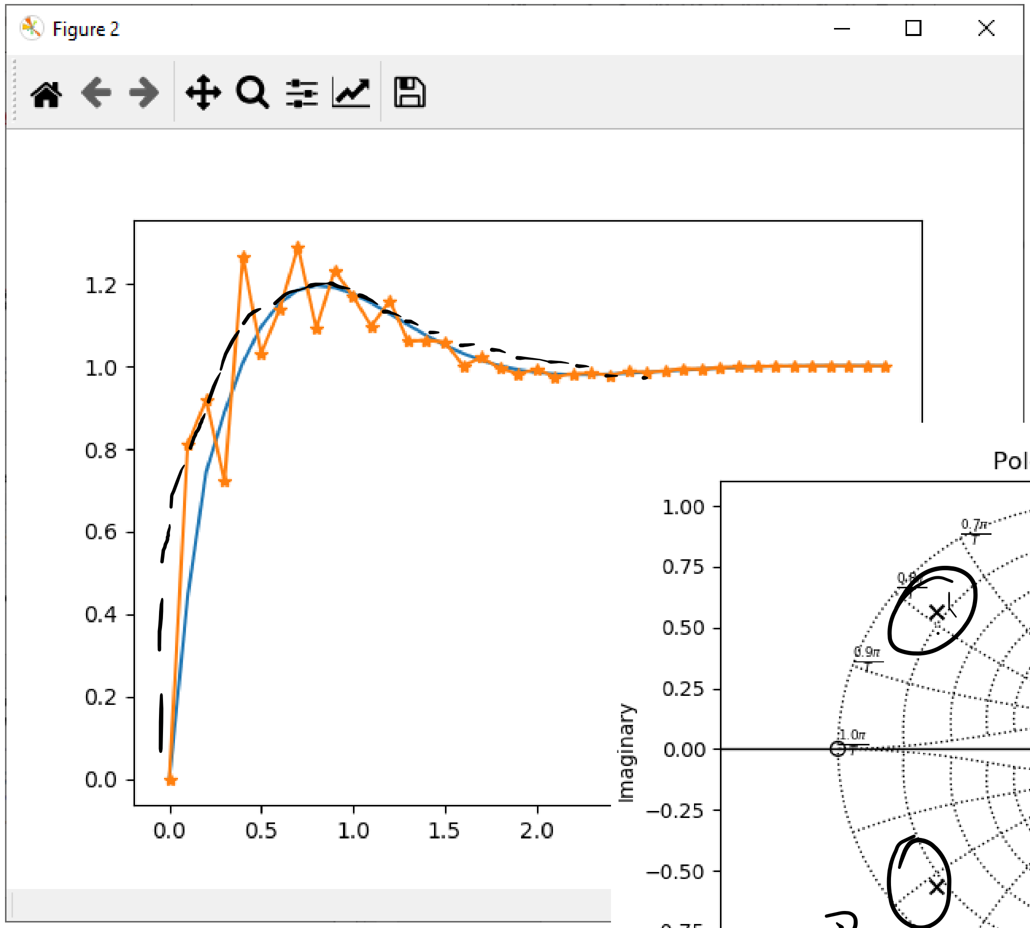


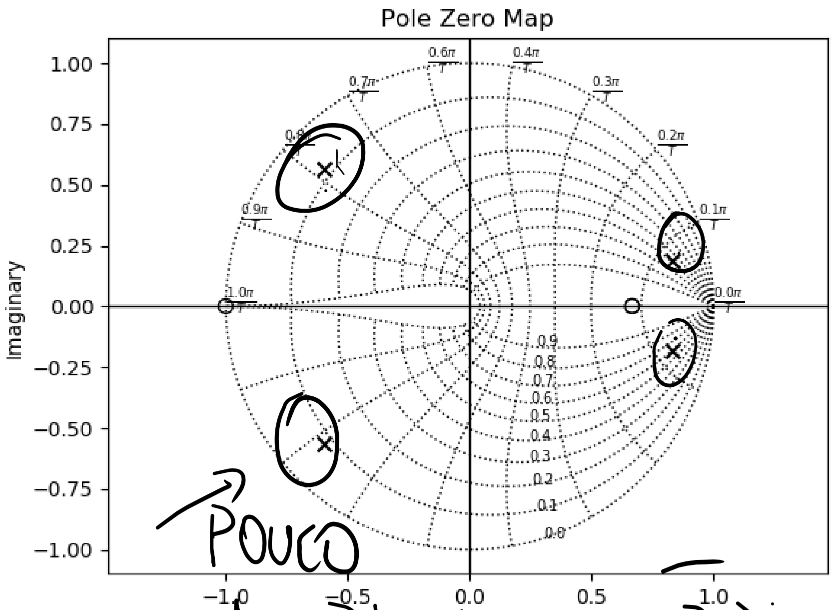


DISCRETIZAÇÃO DO CONTROLE

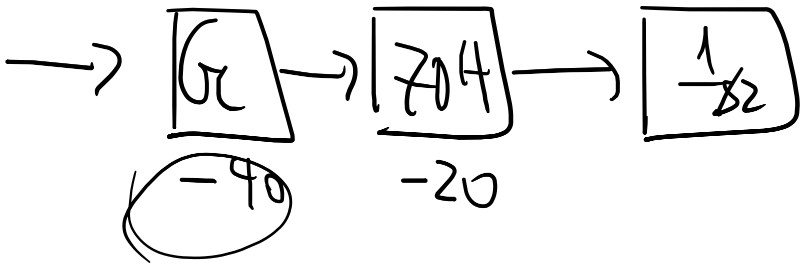








AMORTECIDOS E RAPIDO



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'SettlingMax': 1.2443317227925361,
'Overshoot': 24.359342579093163,
'Undershoot': 0.0,
'Peak': 1.2443317227925361,
'PeakTime': 0.7810310025538723,
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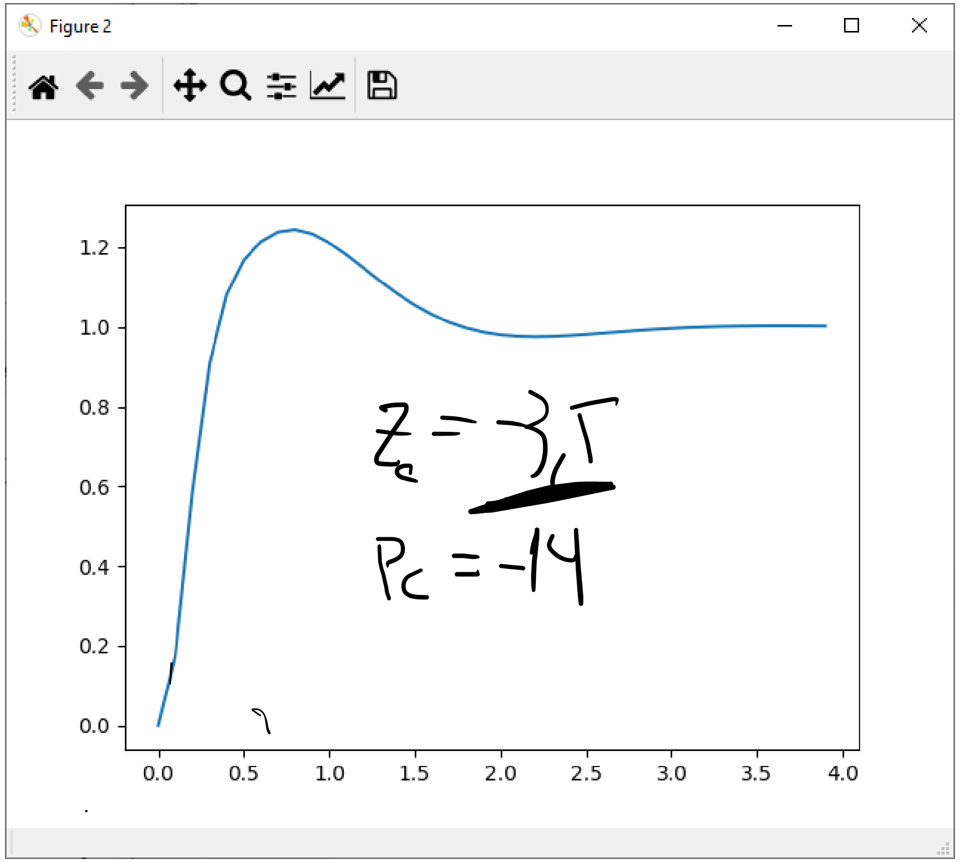
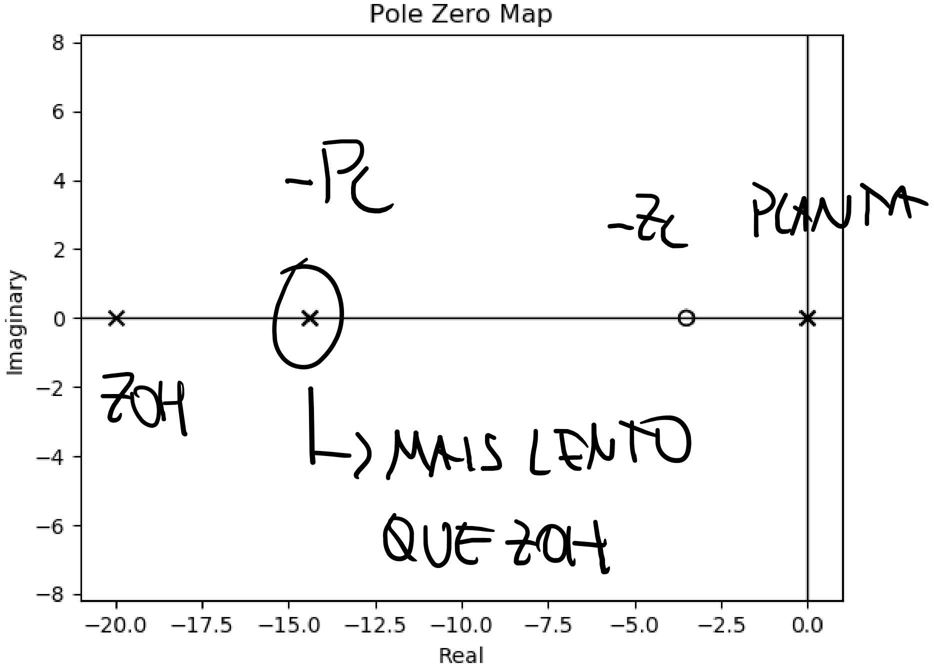
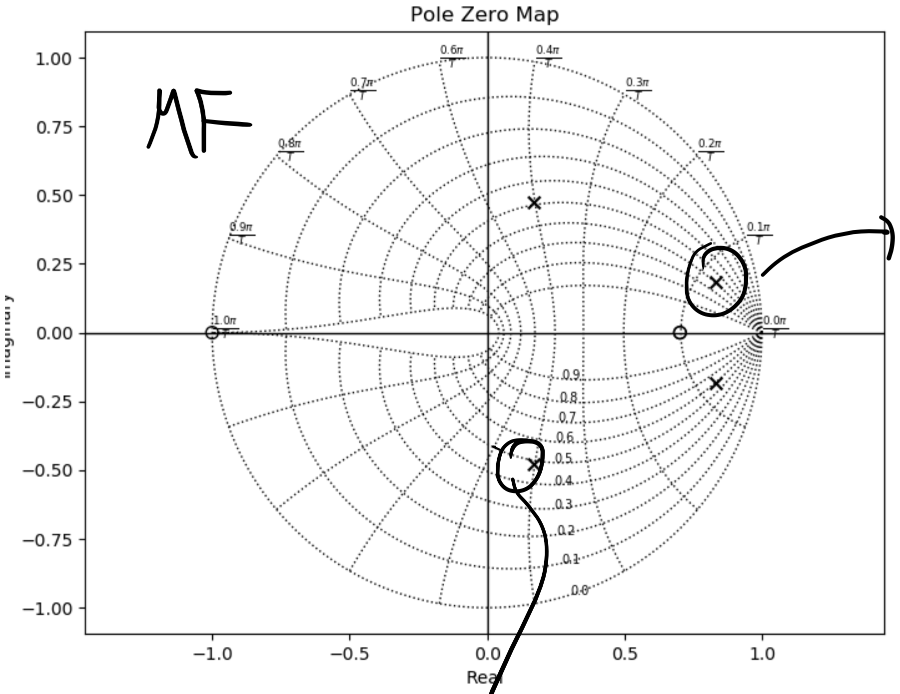
→ POUCO MAIOR QUE 20%







POLOS PRINCIPAIS

POLOS EXTRAS

BEM AMORTECIDO