Reguleringsteknik 1

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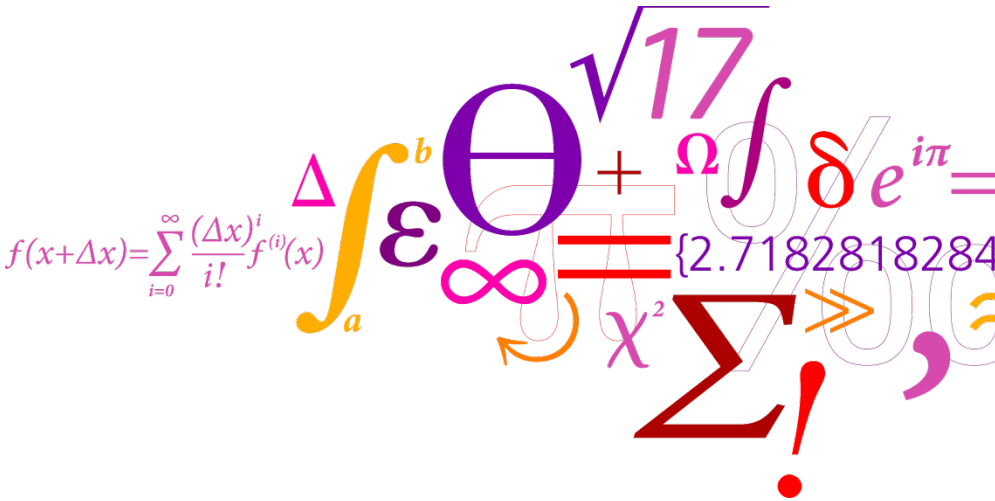
Kursusuge 6

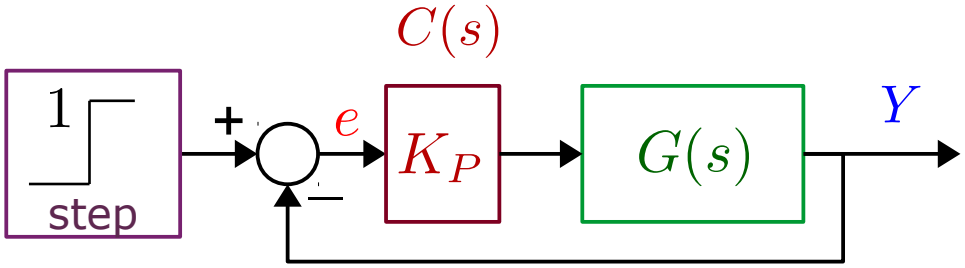
Plan

- Stabilitetsmargin
  - Begreber (igen)
  - Nyquist plot
- PID design ud fra frekvensanalyse
  - P- regulator
  - PI regulator
  - P-Lead regulator



DTU Electrical Engineering
Department of Electrical Engineering

Regulator design



Håndtuning gæt: $K_P = 1$

$$G(s) = \frac{15000}{s^3 + 44s^2 + 784s + 4800}$$

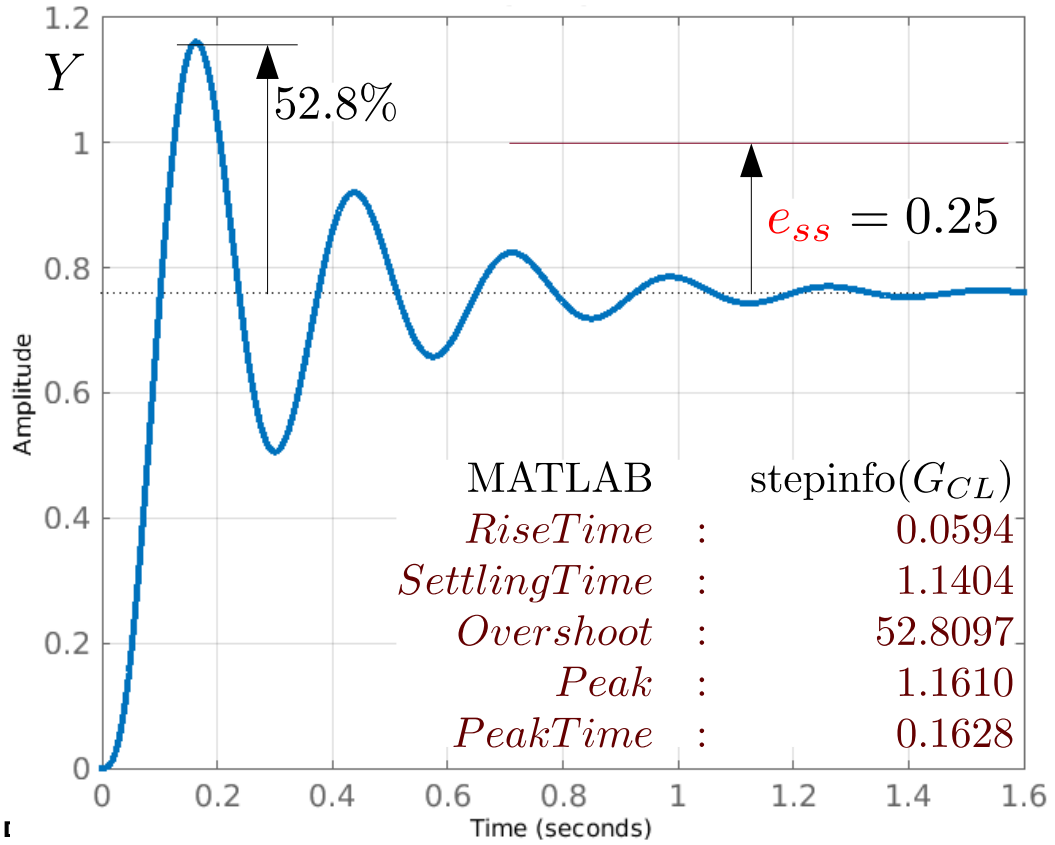
$$G_{å} = 1 \cdot G$$

$$e_{ss,r} = \lim_{s \to 0} \left(\frac{1}{1 + G_{å}} \right)$$

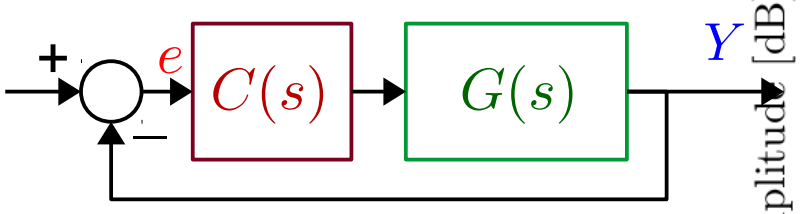
$$e_{ss,r} = \frac{1}{1 + \frac{15000}{4800}}$$

$$e_{ss,r} = 0.25$$

Godt nok?



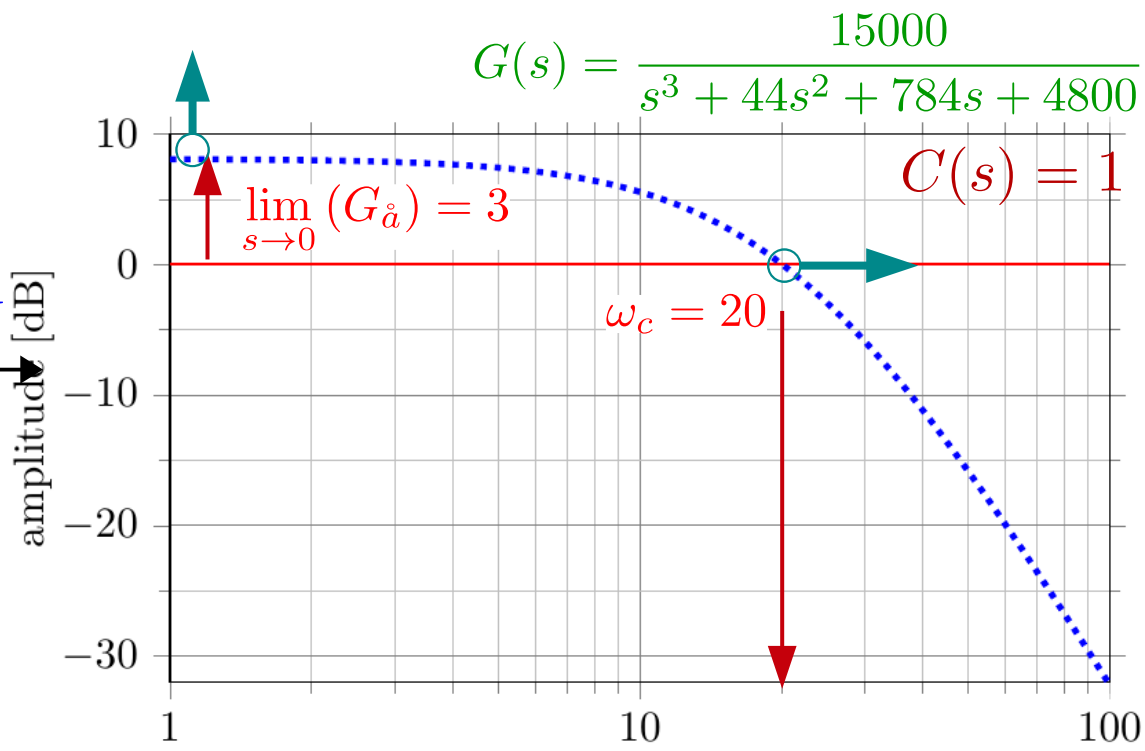
Målsætning

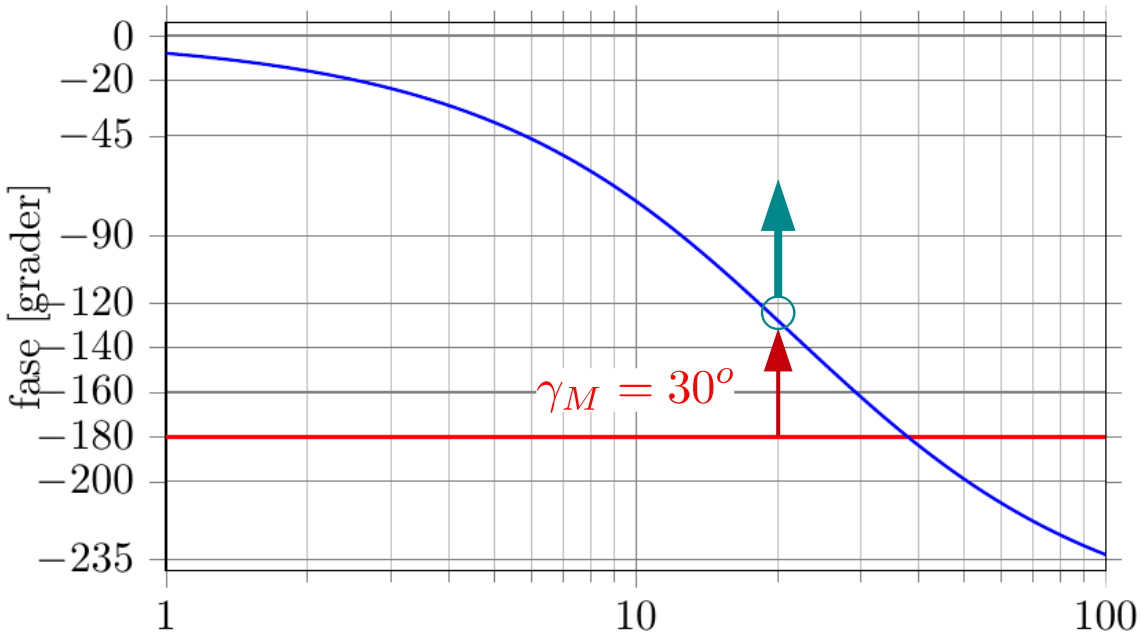


Målsætning (som oftest):

- Lille statisk fejl: $\lim_{s\to 0}(G_{å}) \to \infty$
- Hurtig stigetid (risetime)
  → høj krydsfrekvens
- Stabilt med
  lille oversving (overshoot)
  → stor fasemargin
  → stor gainmargin

Værktøj: PI-Lead





PID designværktøj
I-led

$$G_I = \frac{\tau_i s + 1}{\tau_i s}$$

$$\lim_{s \to 0} (G_I) \to \infty$$

$$N_i = \frac{\omega_c}{\omega_i} \qquad \tau_i = \frac{1}{\omega_i}$$

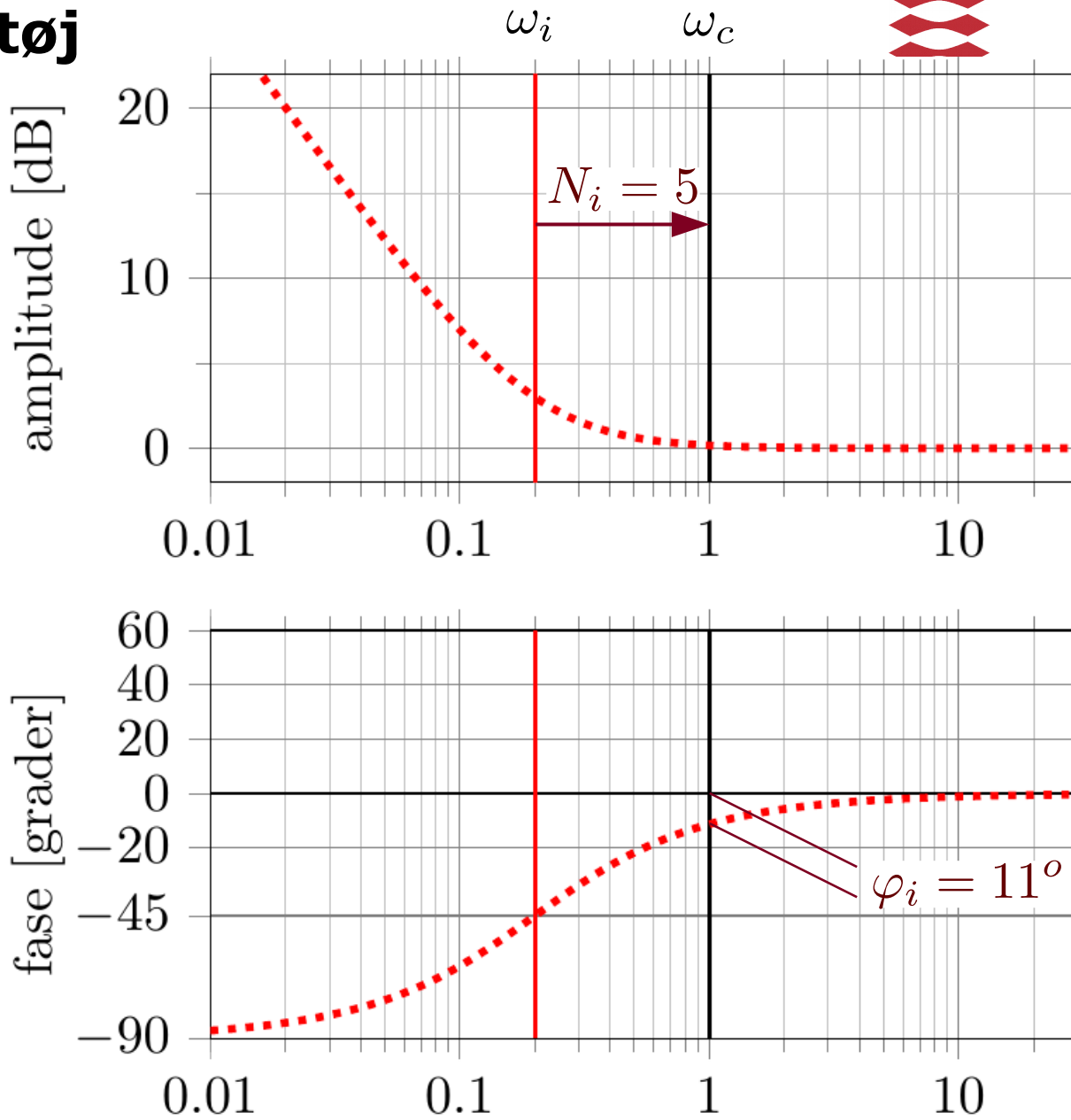
$$\tau_i = \frac{N_i}{\omega_c}$$

Gavner statisk fejl,
Skader fasemargin

$$\varphi_i = \arctan \frac{-1}{N_i}$$

F.eks.

$$N_i = 3 \Rightarrow \varphi_i = -18.4^o$$
$$N_i = 5 \Rightarrow \varphi_i = -11.3^o$$
$$N_i = 8 \Rightarrow \varphi_i = -7.1^o$$



PID designværktøjer
Lead led

$$G_L(s) = \frac{\tau_d s + 1}{\alpha \tau_d s + 1}$$

$$\tau_d = \frac{1}{\sqrt{\alpha}\ \omega_c}$$

- Forbedre fasemargin med op til φ_m
- Øger gain ved ω_c

$$\varphi_m = \arcsin \frac{1-\alpha}{1+\alpha}$$

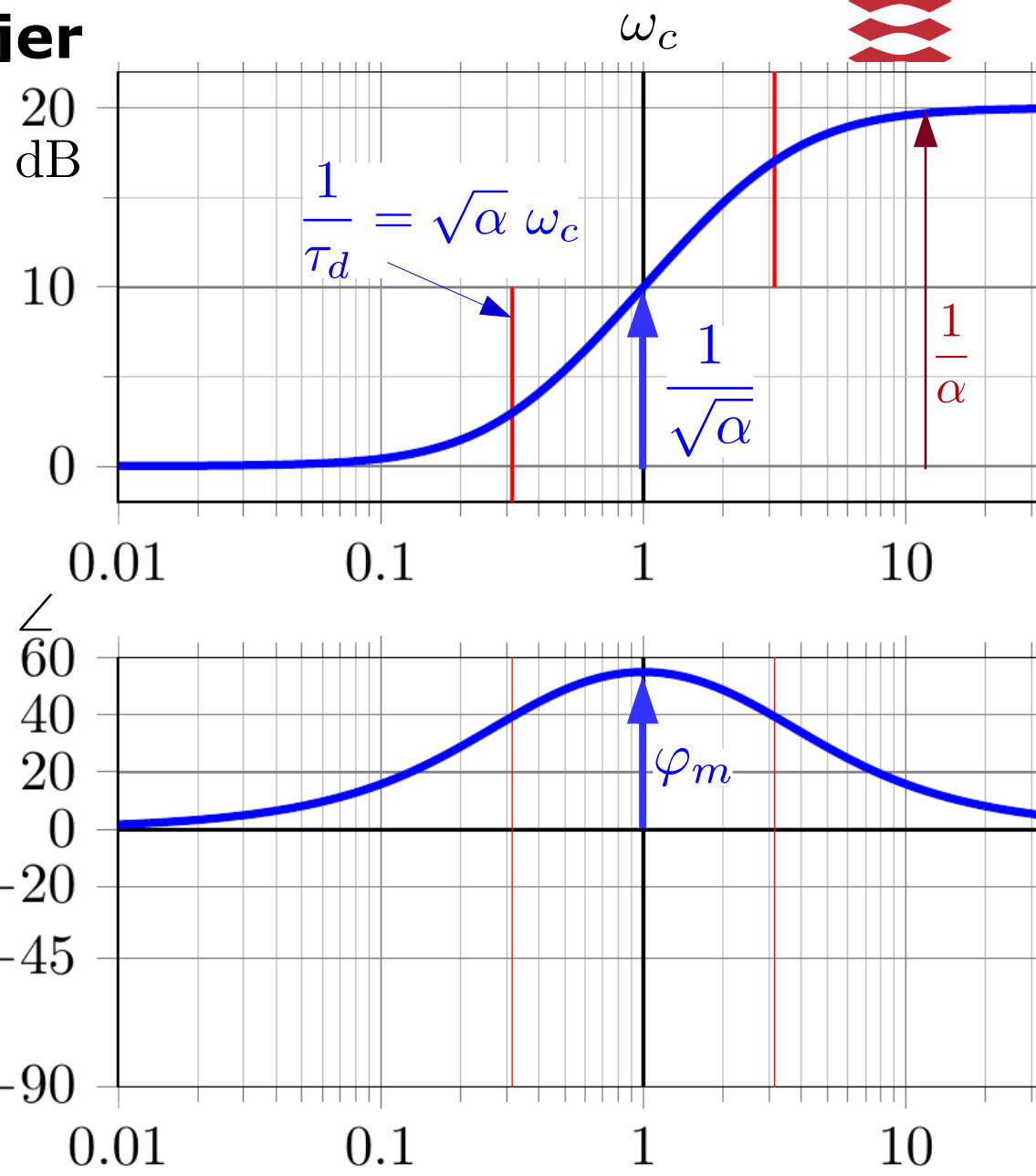
$$|G_L(j\omega_c)| = \frac{1}{\sqrt{\alpha}}$$

F.eks.

$\alpha = 0.1 \Rightarrow \varphi_m = 54^o,\ 3.2\ (10\text{dB})$

$\alpha = 0.2 \Rightarrow \varphi_m = 42^o,\ 2.2\ (7\text{dB})$

$\alpha = 0.5 \Rightarrow \varphi_m = 19^o,\ 1.4\ (3\ \text{dB})$



PID-værktøj
I-led + Lead led

Samlet forbedring af fasemargin:

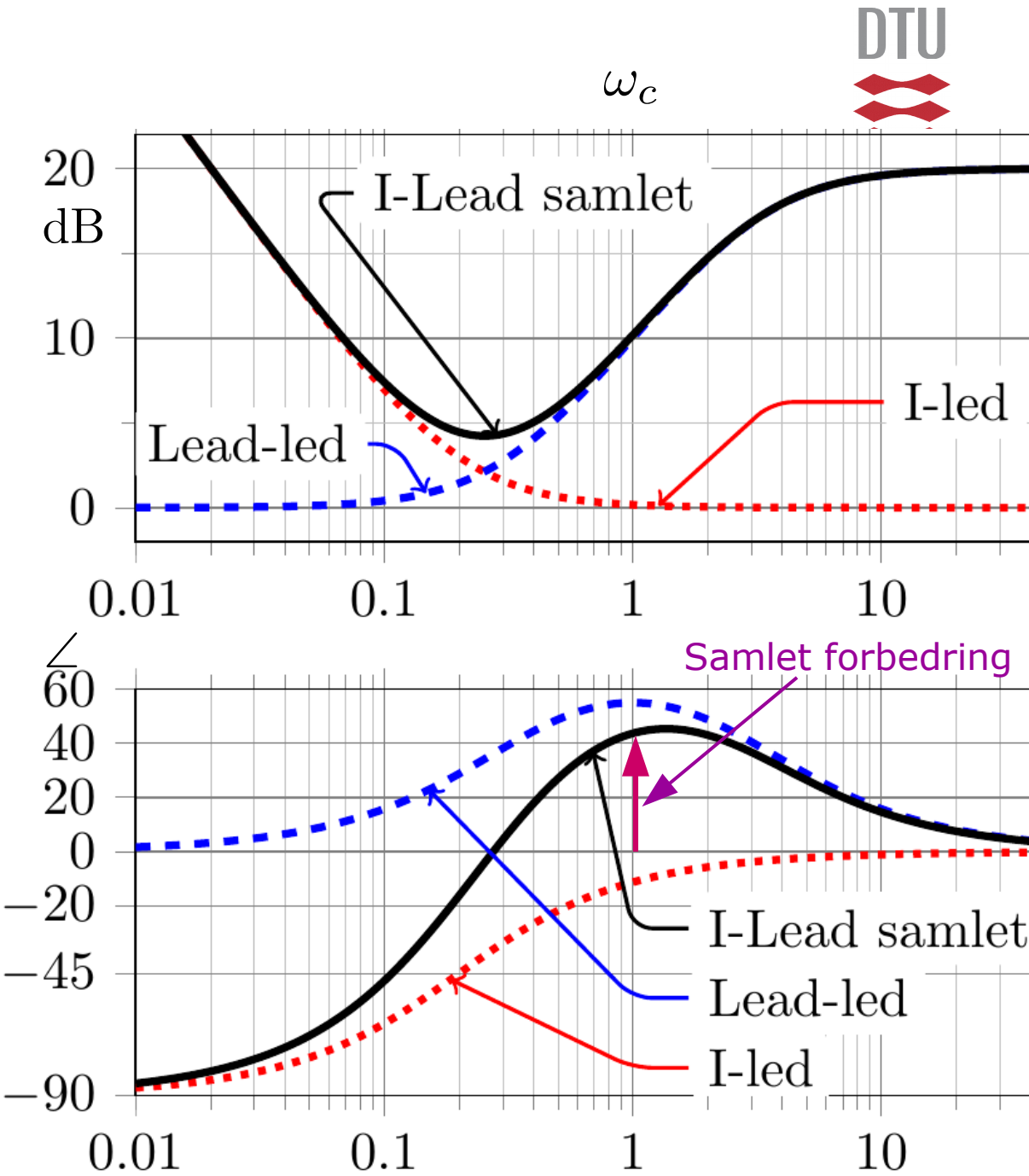
positiv negativ

$$\varphi_{m+i} = \varphi_m + \varphi_i$$

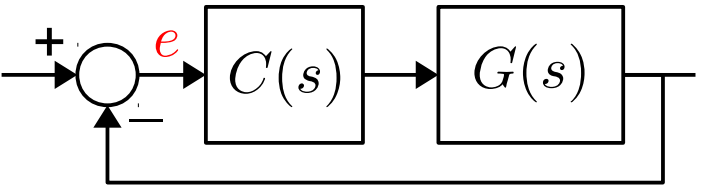
F.eks.:

$$N_i = 5, \quad \alpha = 0.1$$

$$\varphi_{m+i} = 44^o$$



Metode



$$G_{å}(s) = K_P \frac{\tau_i s + 1}{\tau_i s} \frac{\tau_d s + 1}{\alpha \tau_d s + 1} G(s)$$

Metode

1)Vælg en N_i og α

2)Find forbedring af fasemargin φ_{m+i}

3)Vælg en ønsket fasemargin γ_M

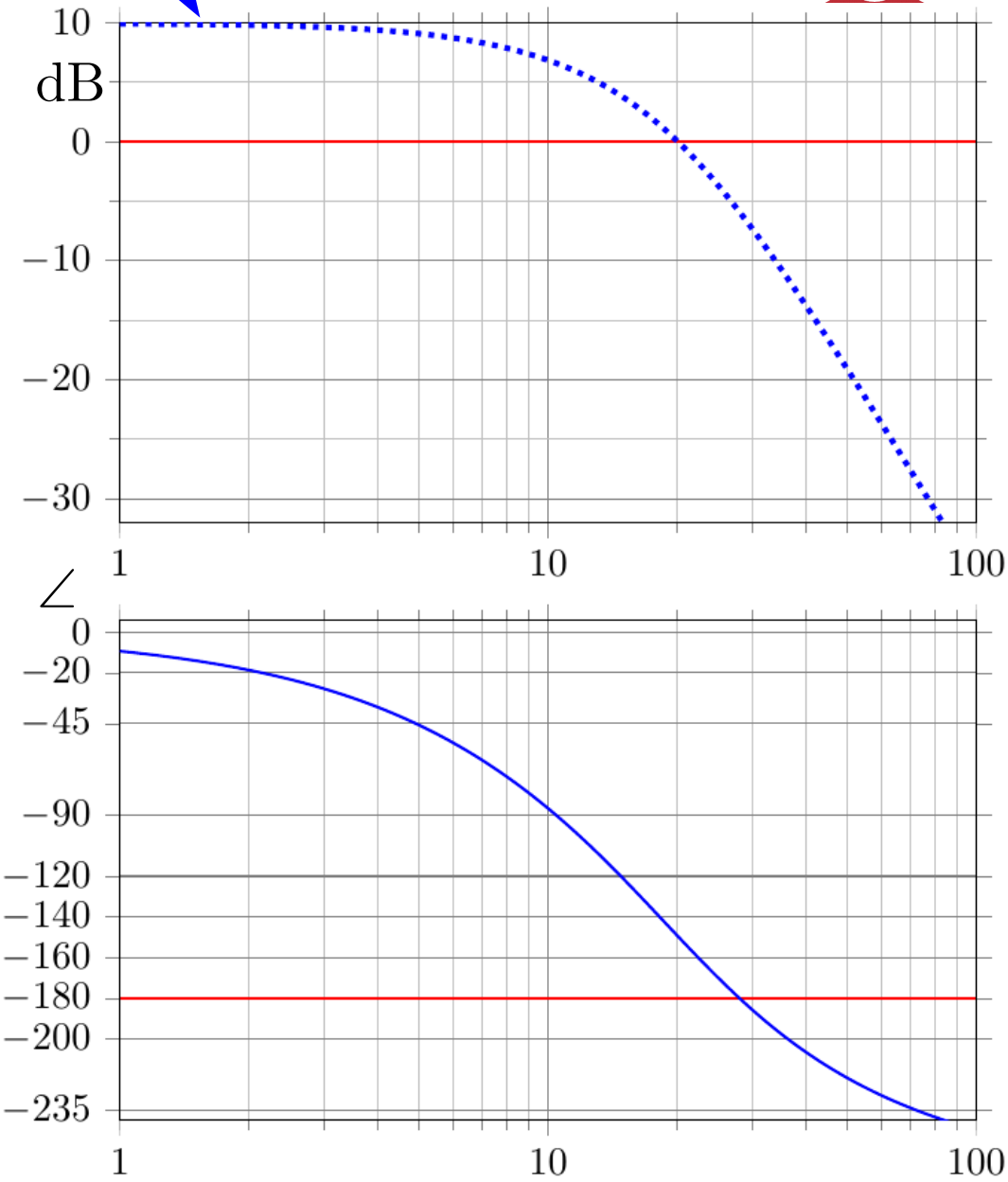
4)Find ny krydsfrekvens ω_c ved $\angle G = -180 + \gamma_M - \varphi_{m+i}$

5) $\omega_m = \omega_c$ Beregn τ_i, τ_d

6)Find ny $K_P = \left| \frac{1}{C(j\omega)G(j\omega)} \right|_{\omega=\omega_c}$

$$G(s) = \frac{15000}{s^3 + 44s^2 + 784s + 4800}$$

DTU



PID design
- find ny krydsfrekvens

Valg: $\alpha = 0.2$

$N_i = 3$

$\gamma_m = 60^o$

Beregn:

$$\varphi_i = \arctan\left(\frac{-1}{N_i}\right) = -18.4^o$$

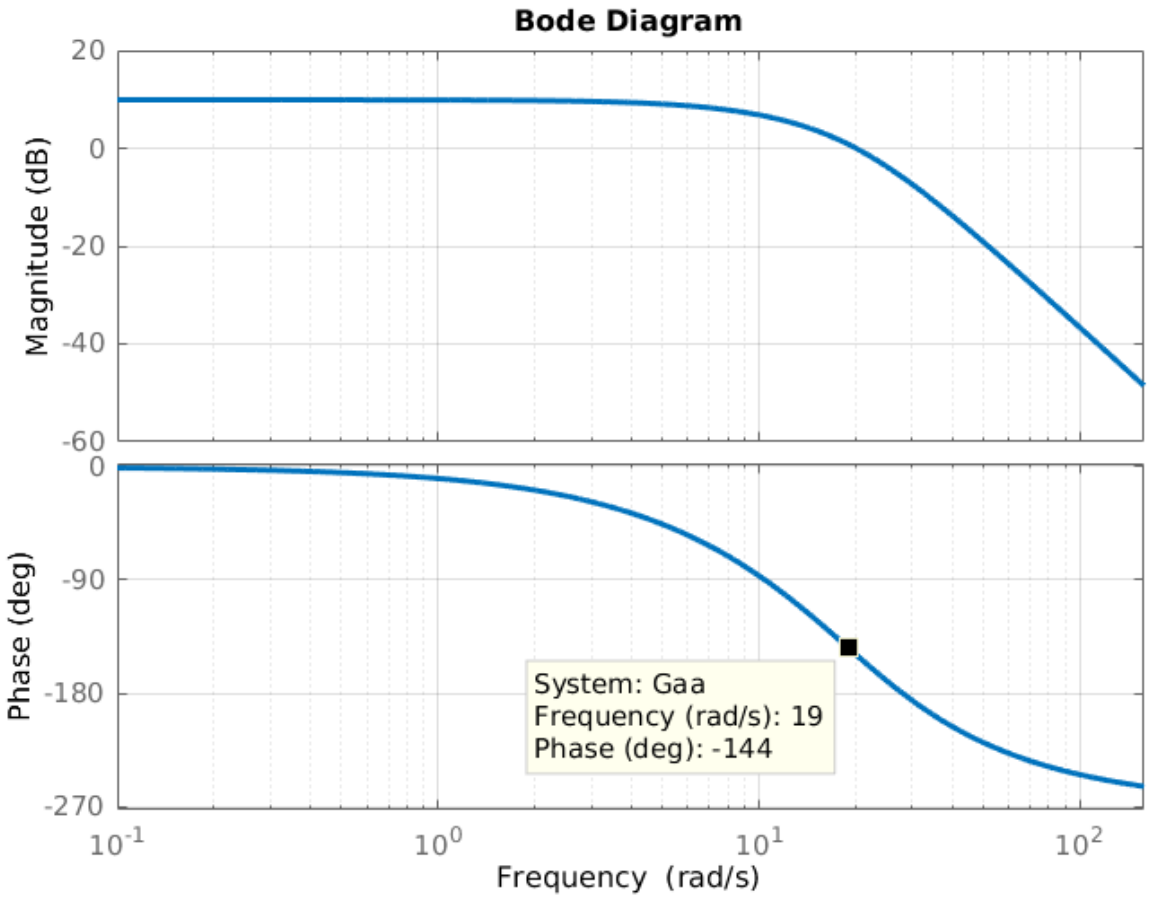
$$\varphi_m = \arcsin\frac{1-\alpha}{1+\alpha} = 42^o$$

$$-180 + \gamma_M - \varphi_m - \varphi_i = -143.6^o$$

$$\omega_c = \omega\,|\angle G(j\omega) = -143.6^o$$

Find krydsfrekvens:

$$\omega_c = 19\ rad/sec$$



PID design
- beregn I- og Lead-led

Kendt

$$\alpha = 0.2$$

$$N_i = 3$$

$$\gamma_m = 60^o$$

$$\omega_c = 19\ rad/sec$$

I-led

$$G_i = \frac{\tau_i s + 1}{\tau_i s}$$

$$\tau_i = \frac{N_i}{\omega_c}$$

$$\tau_i = \frac{3}{19} = 0.158$$

$$G_i = \frac{0.158s + 1}{0.158s}$$

Lead-led

$$G_d = \frac{\tau_d s + 1}{\alpha \tau_d s + 1}$$

$$\tau_d = \frac{1}{\omega_c \sqrt{\alpha}}$$

$$\tau_d = \frac{1}{19\sqrt{0.2}} = 0.118$$

$$G_d = \frac{0.118s + 1}{0.0236s + 1}$$

PID design
- find Kp

$$\omega_c = 19\ rad/sec$$

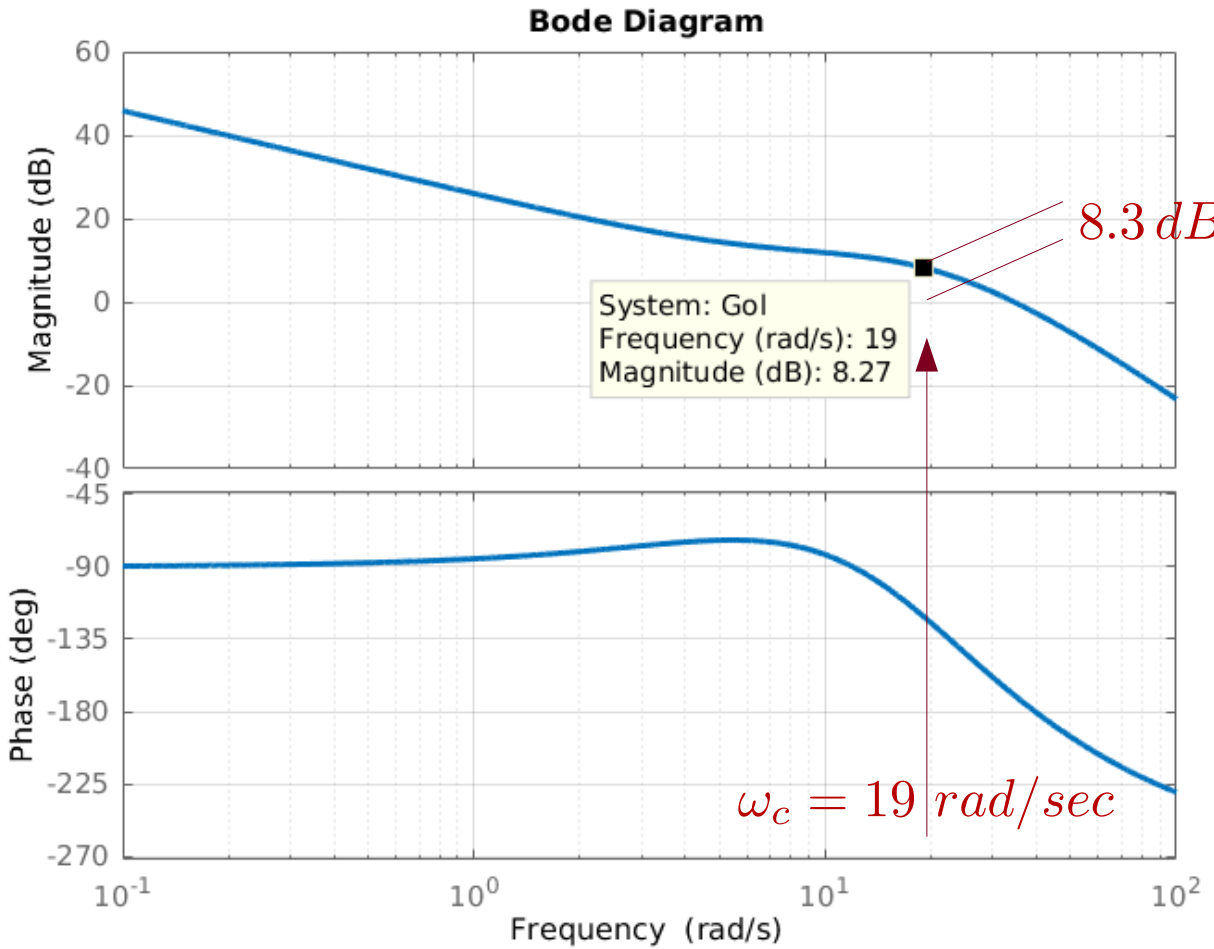
$$G_i = \frac{0.158s + 1}{0.158s}$$

$$G_d = \frac{0.118s + 1}{0.0236s + 1}$$

$$K_P = \left| \frac{1}{G_i G_d G} \right|_{s=j\,\omega_c}$$

MATLAB:
[M,P] = bode(Gi*Gd*G, 19)
Kp = 1/M

$$K_P = 0.38 \quad (-8.3\,dB)$$



PID design
Check open loop bodeplot

$\alpha = 0.2$

$N_i = 3$

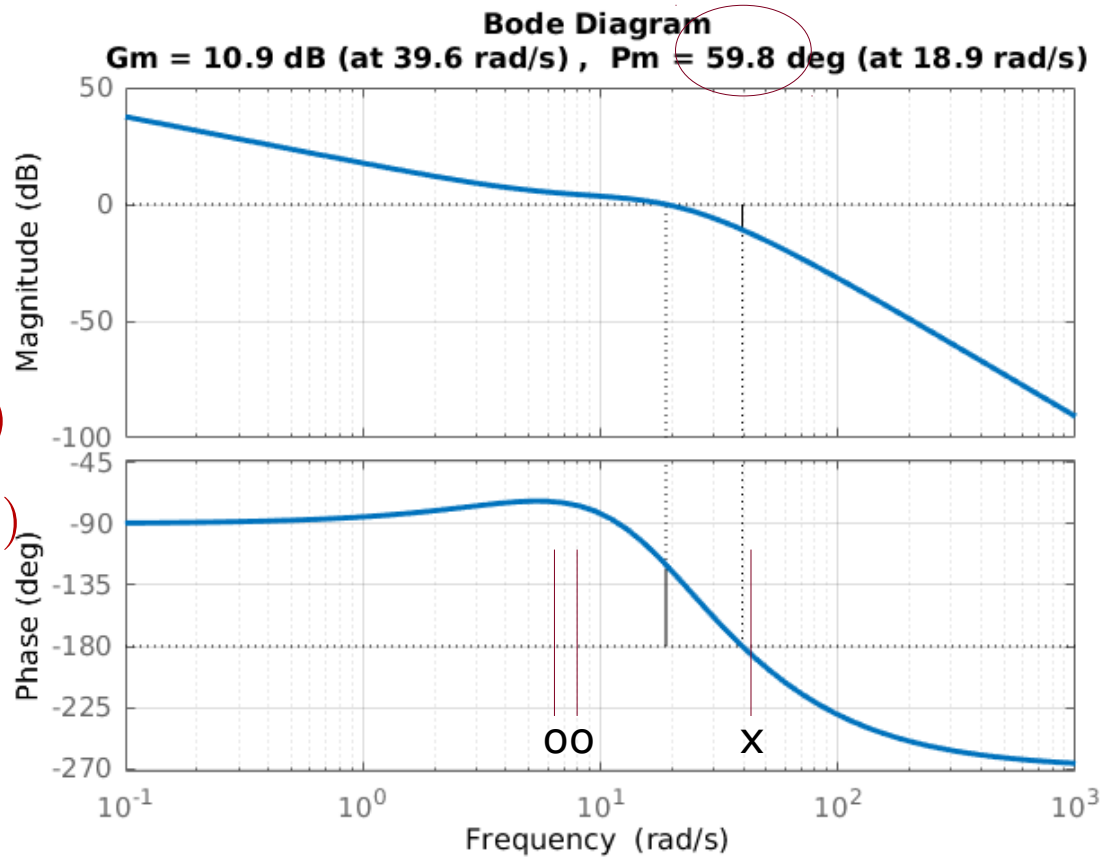
$\gamma_m = 60^o$

$\omega_c = 19\ rad/sec$

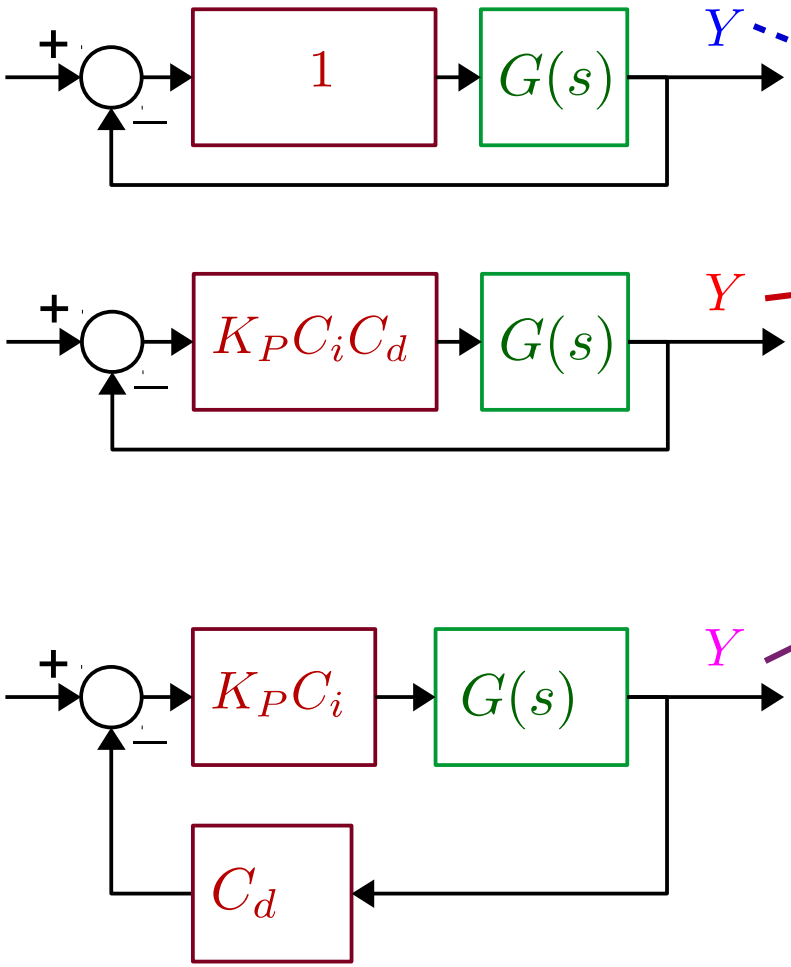
$\tau_i = 0.158 \quad (\omega_i = 6.3\ rad/s)$

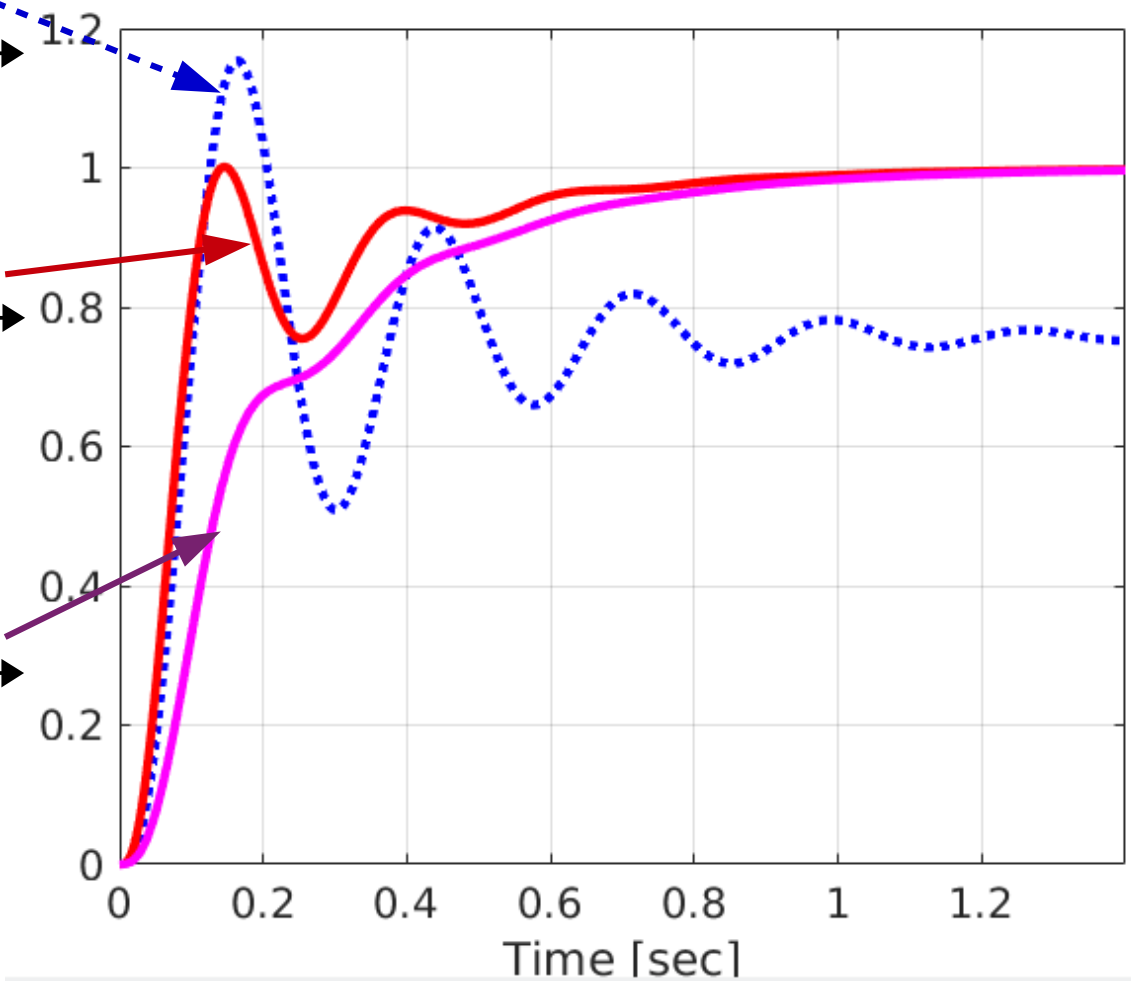
$\tau_d = 0.118 \quad (\omega_d = 8.4\ rad/s)$

$K_P = 0.38$



PID-design
Step respons vurdering





Grupperegning og Dagens øvelse

- Grupperegning – PI-Lead
- Øvelse 6+7+8 dampmaskineprojekt (til rapport 2)
- Næste gang: bl.a. midtvejstest og midtvejsevaluering