Reguleringsteknik 1

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Kursusuge 9

Plan

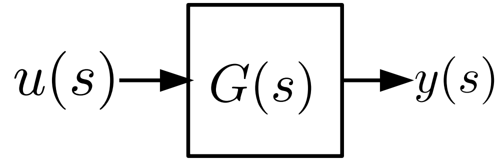
- Begrænsede systemer
  - Rate limiter
  - Integrator wind up

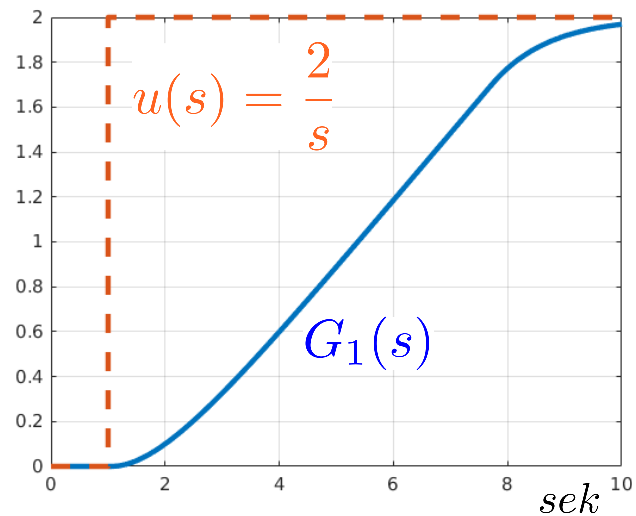
Grupperegning

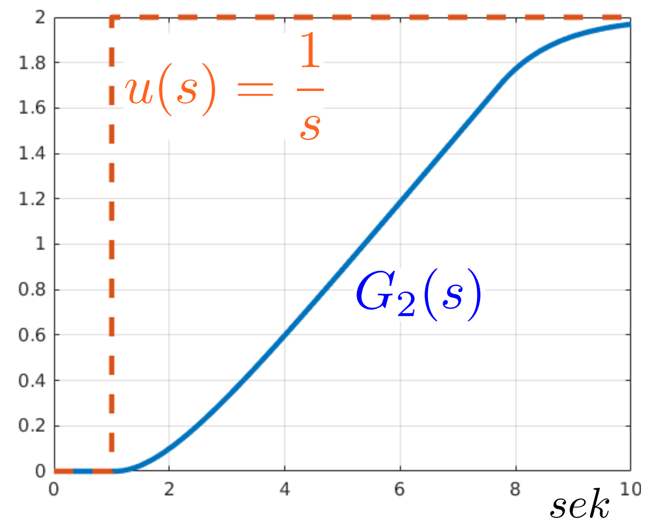
- Regulator for begrænset system
- Multiple choice opgaver på campusnet

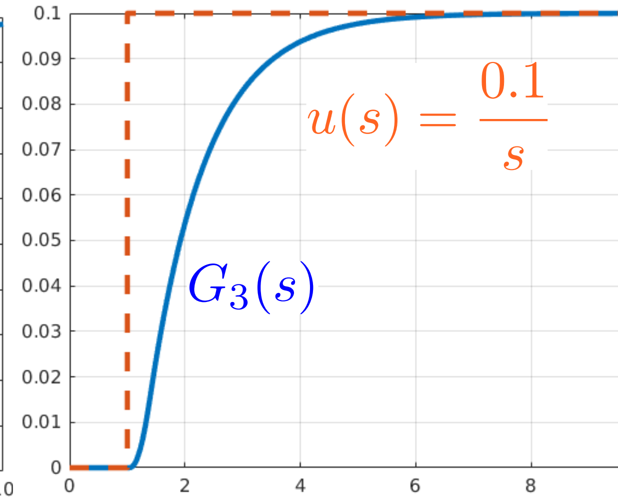
DTU Electrical Engineering
Department of Electrical Engineering

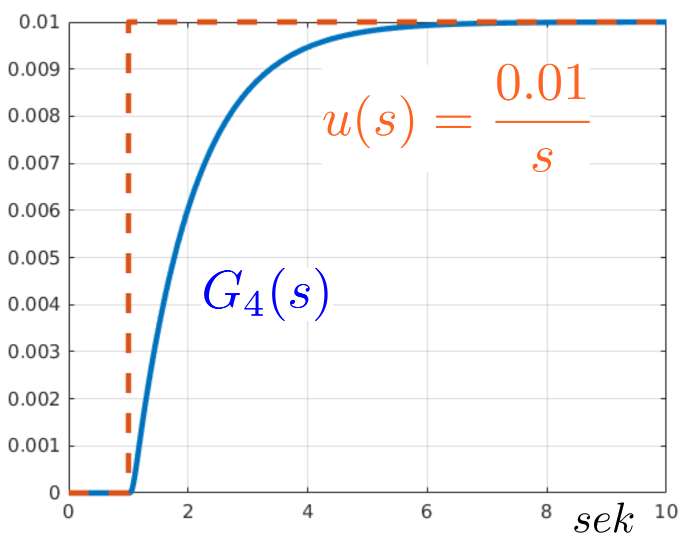
Limited systems
- step respons

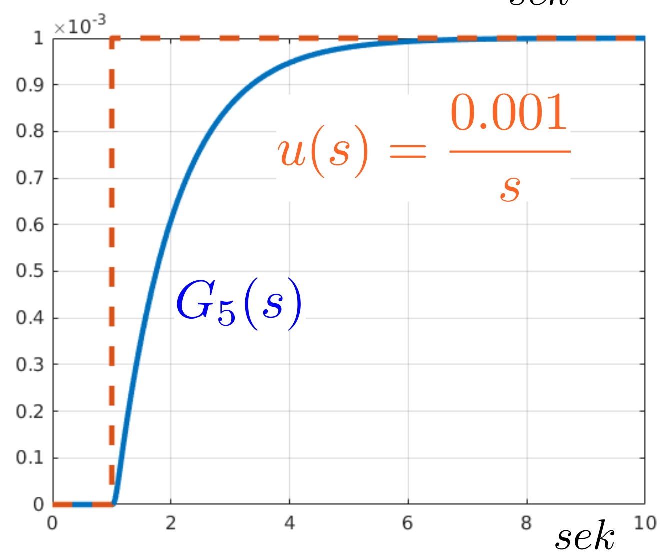










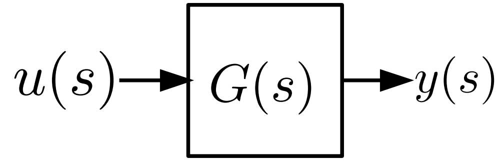


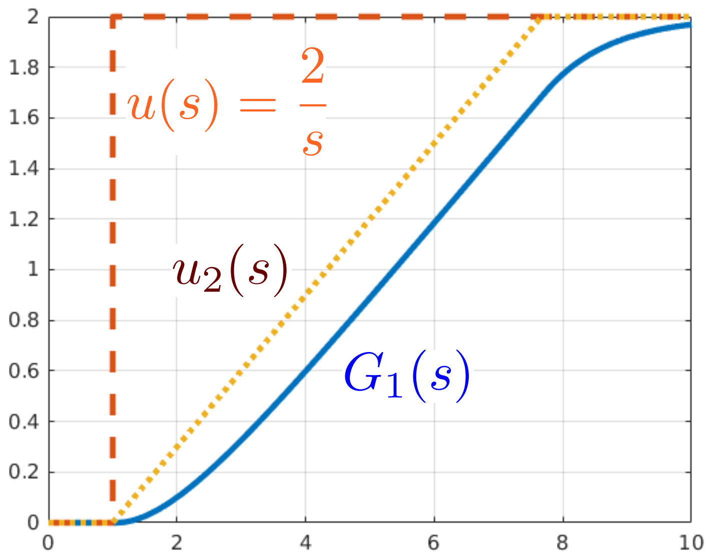
G1, G2 og G3
ligner 2. orden?

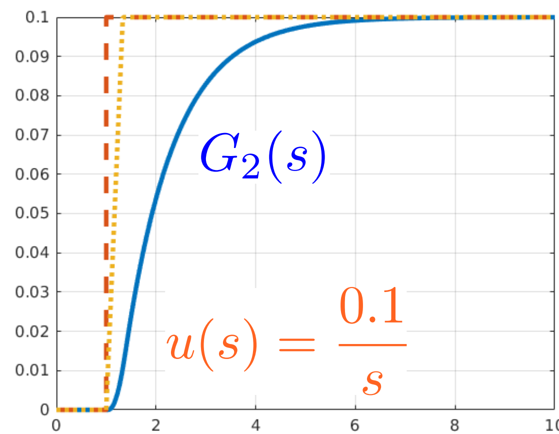
G4 = G5
ligner 1. orden:

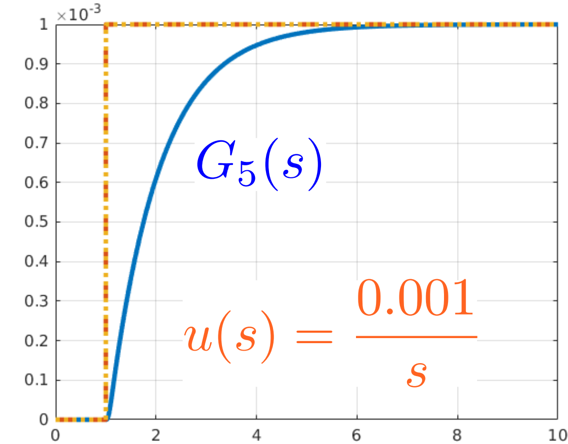
$$G_5(s) \approx \frac{1}{s+1}$$

Rate-limited system



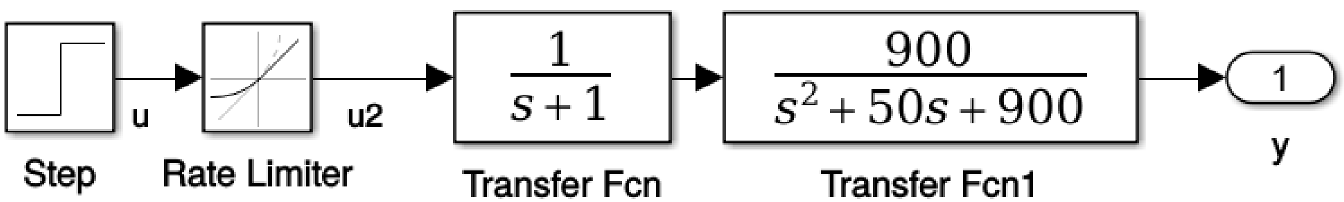






Samme system!

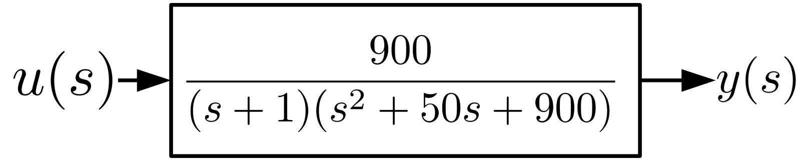
G1 = G2 = G3 = G4 = G5



Rate limiter: 0.3/sek

Modellering viser kun sand dynamik ved små signaler (her step < 0.01), og Dynamik domineres af $\frac{1}{s+1}$

Rate-limited system Regulator design



Regulator design

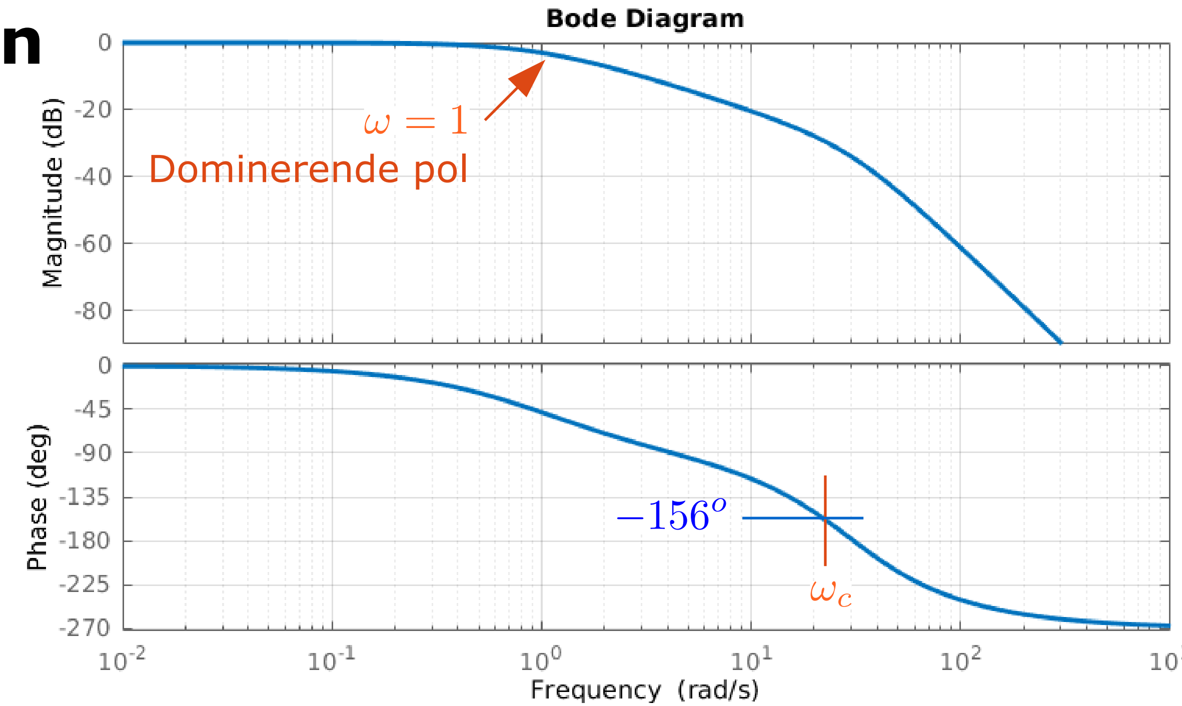
$$N_i = 3,\ \alpha = 0.1,\ \gamma_M = 60^o$$

$$\varphi_i = -\arctan\frac{1}{N_i} = -18^o$$

$$\varphi_d = \arcsin\frac{1-\alpha}{1+\alpha} = 55^o$$

$$\angle G(\omega_C) = -180 + \gamma_M - \varphi_i - \varphi_d$$

$$\angle G(\omega_C) = -156^o$$

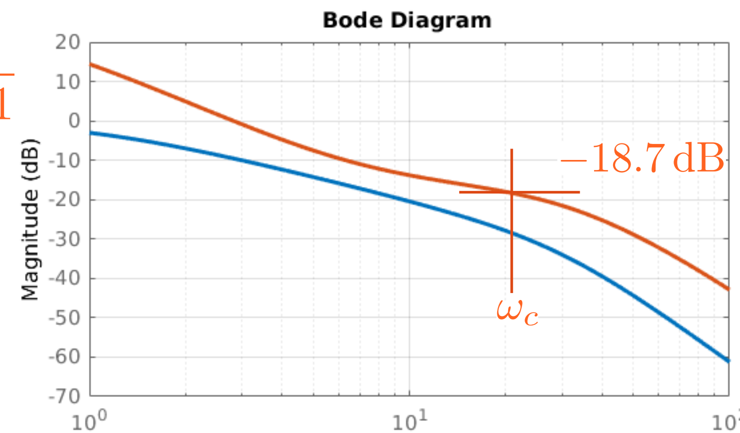


$$\omega_c = 22\,\mathrm{rad/sek}$$

$$C_i(s) = \frac{\tau_i s + 1}{\tau_i s} \qquad C_d(s) = \frac{\tau_d s + 1}{\alpha\tau_d s + 1}$$

$$\tau_i = \frac{N_i}{\omega_c} = 0.137$$

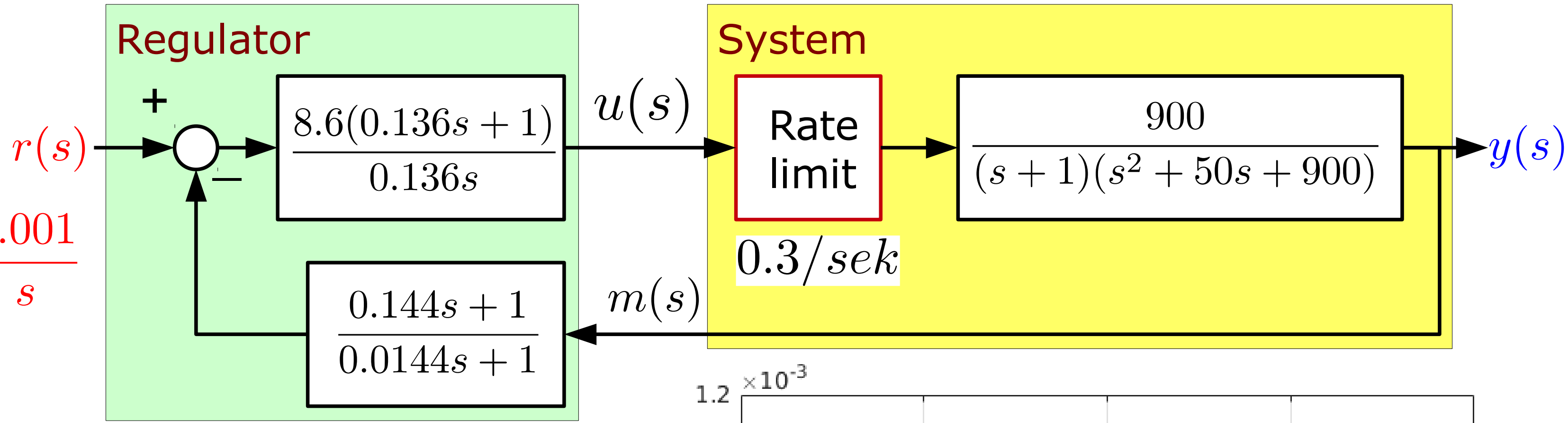
$$\tau_d = \frac{1}{\omega_c\sqrt{\alpha}} = 0.144$$



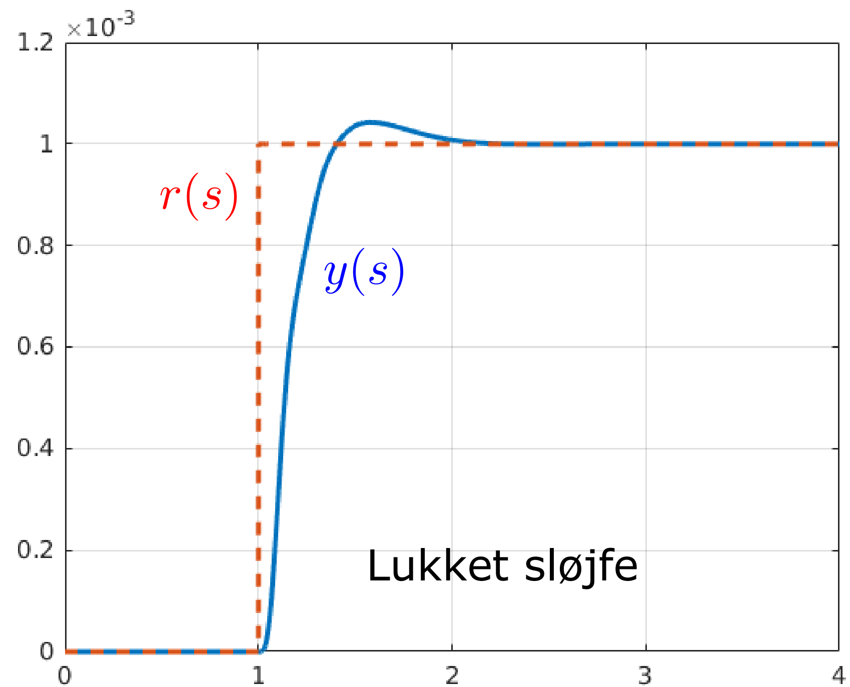
$$K_P = 18.7\,\mathrm{dB}$$

$$K_P = 8.6$$

Rate-limited system Regulator validering

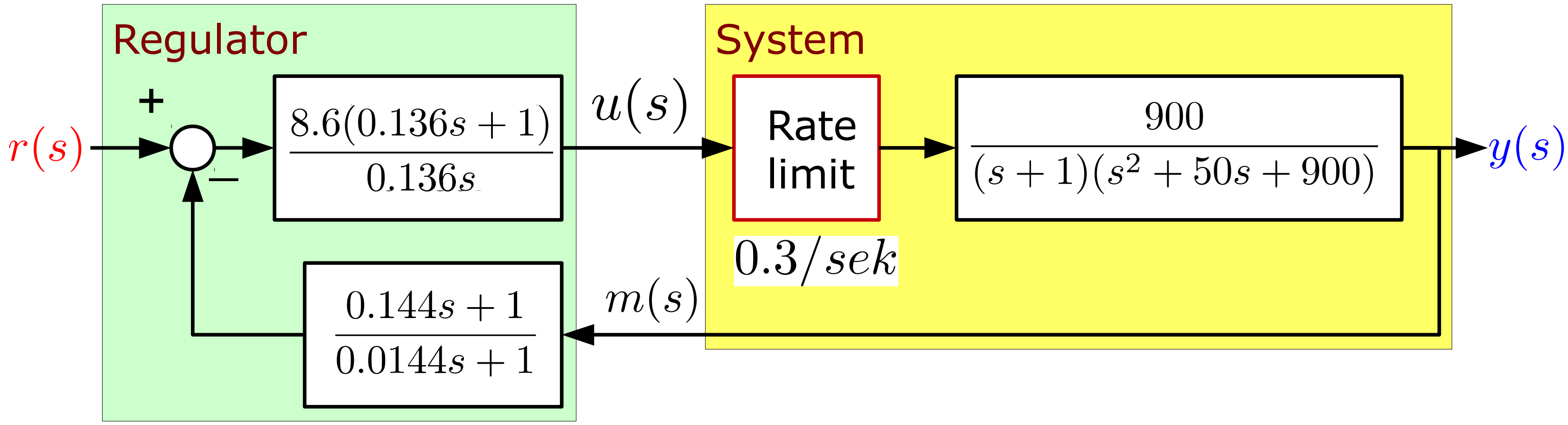


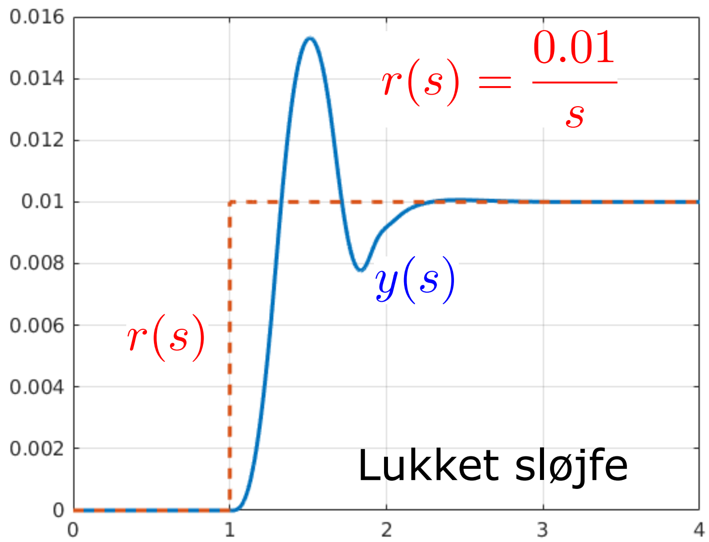
$$r(s) = \frac{0.001}{s}$$

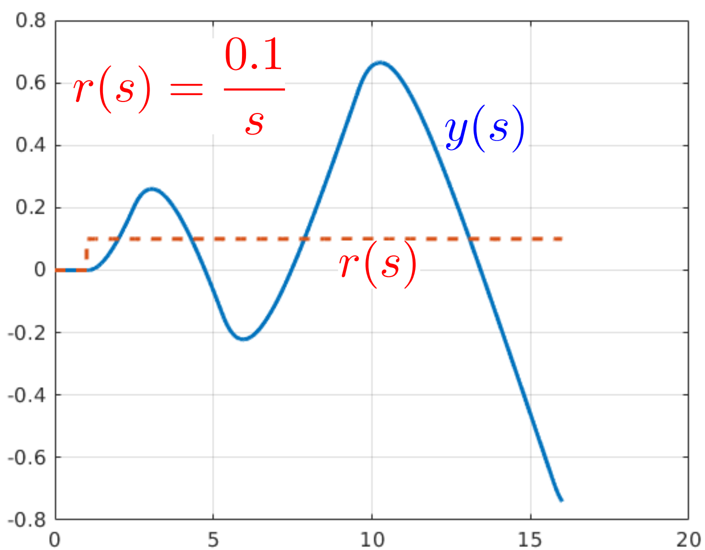


Er det så fint?
Hvad med rate limiter?

Rate-limited system
Regulator validering







Hvad kan gøres?
- fjern rate limiter
- redesign

Bruges rate limiter?
Ja, for at reducere slid.

Rate-limited Regulator re-design

$$u(s) \rightarrow \boxed{G_{sys} \quad \frac{900}{(s+1)(s^2+50s+900)}} \rightarrow y(s)$$

Regulator design

$$N_i = 3,\ \alpha = 0.1,\ \gamma_M = 60^o$$

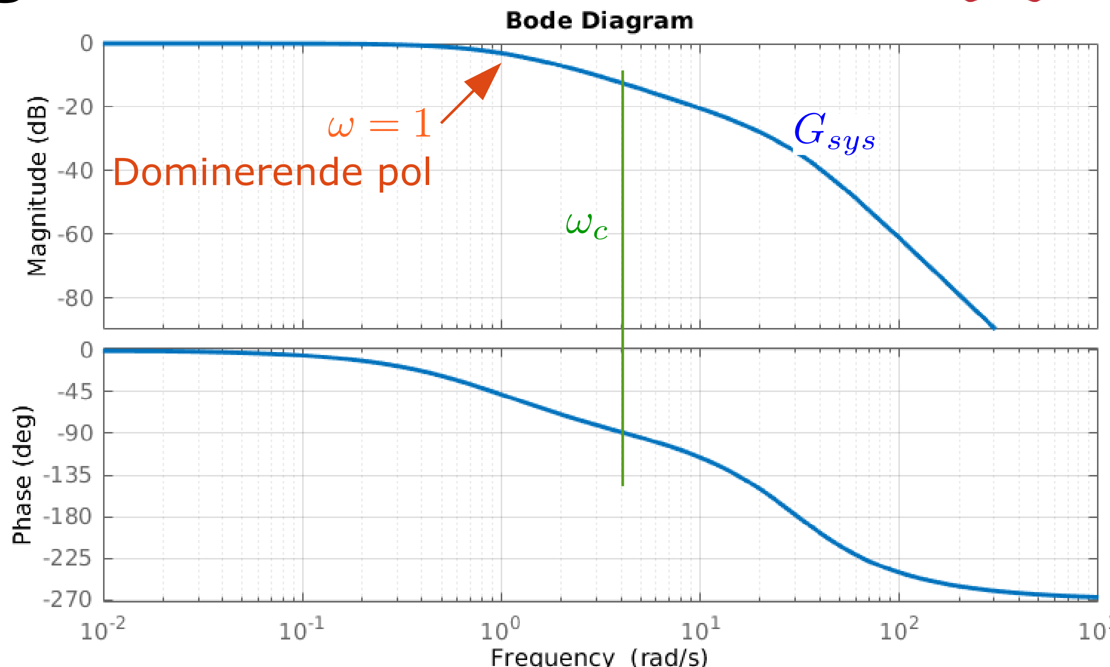
Re-design med **valgt** $\omega_c = 4\,\mathrm{rad/sek}$

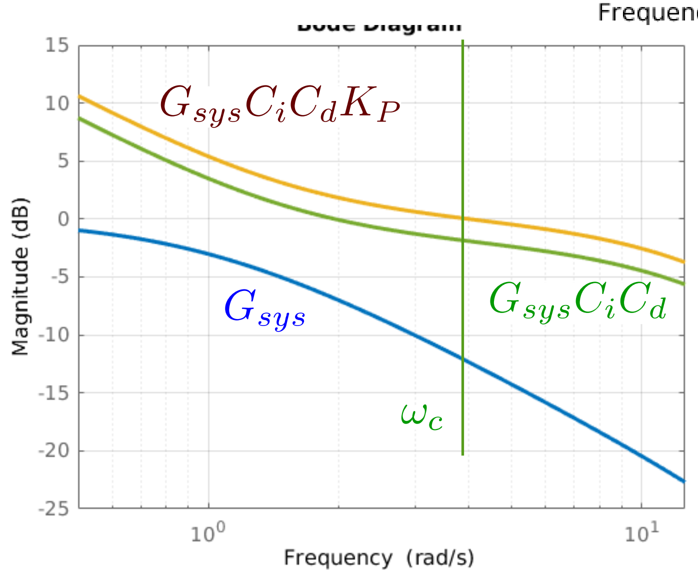
$$\tau_i = \frac{N_i}{\omega_c} = 0.75$$

$$\tau_d = \frac{1}{\omega_c\sqrt{\alpha}} = 0.79$$

$$C_i(s) = \frac{\tau_i s + 1}{\tau_i s}$$

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

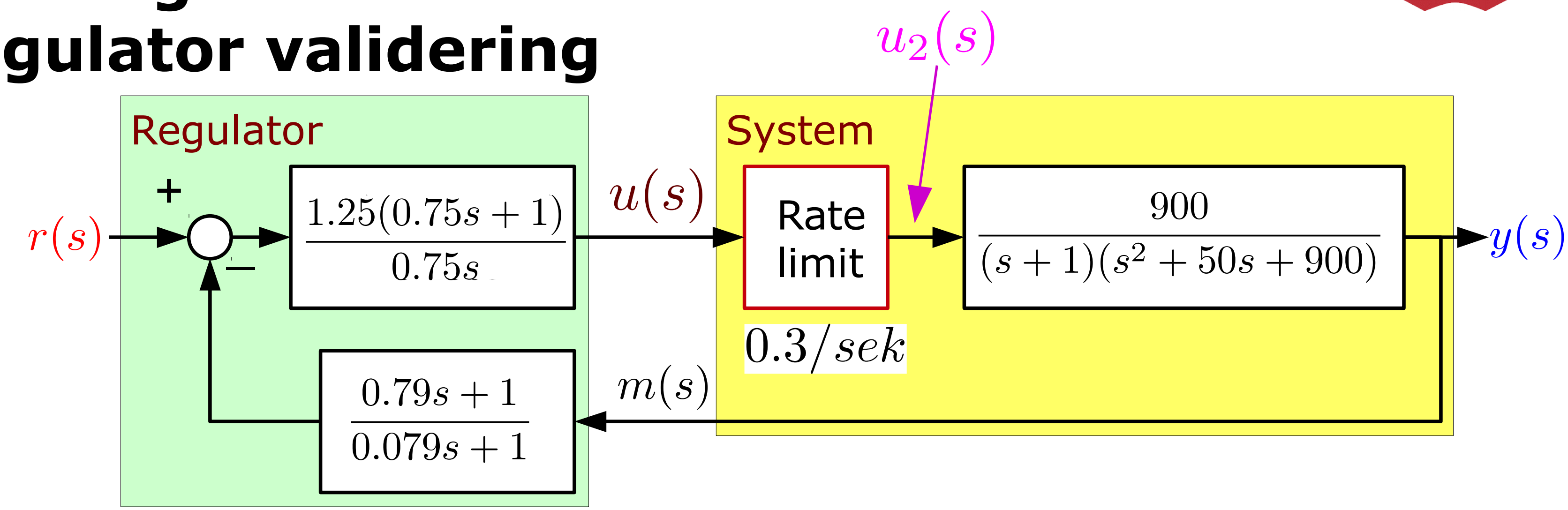


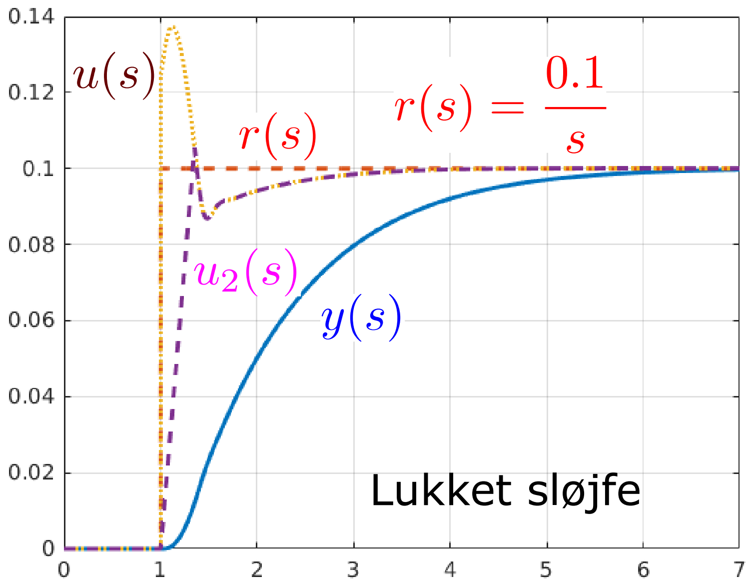


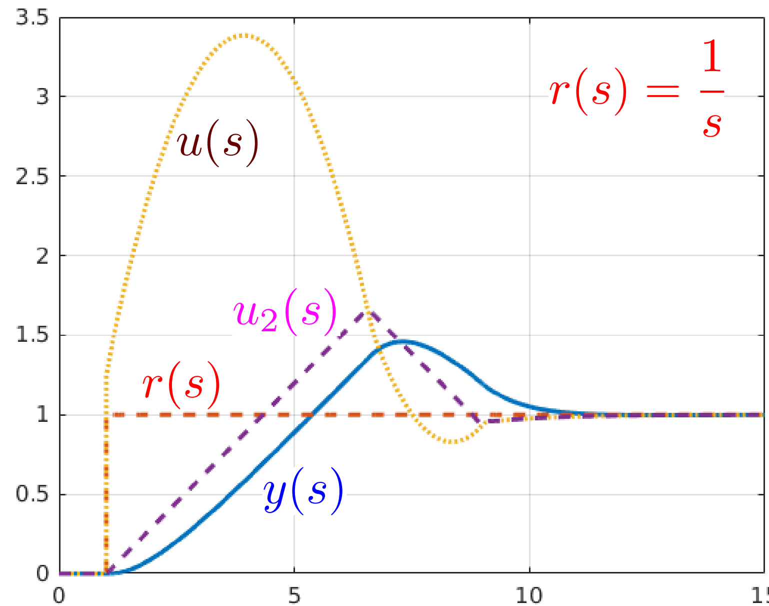
$$K_P = 1.9\,\mathrm{dB}$$

$$K_P = 1.25$$

Rate-limited
re-designed
Regulator validering







Begrænsede systemer
Kontrolspørgsmål

a) Er et rate-limited system ulinært?

b) Hvordan findes overføringsfunktion for rate-limeted system?

c) Kan en rate-limited system med et stabilt designet regulator
være ustabil?

d) Hvordan designes en stabil regulator til et rate-limited system?

Begrænsede systemer
Kontrolspørgsmål

a) Er et rate-limited system ulinært?
Ja

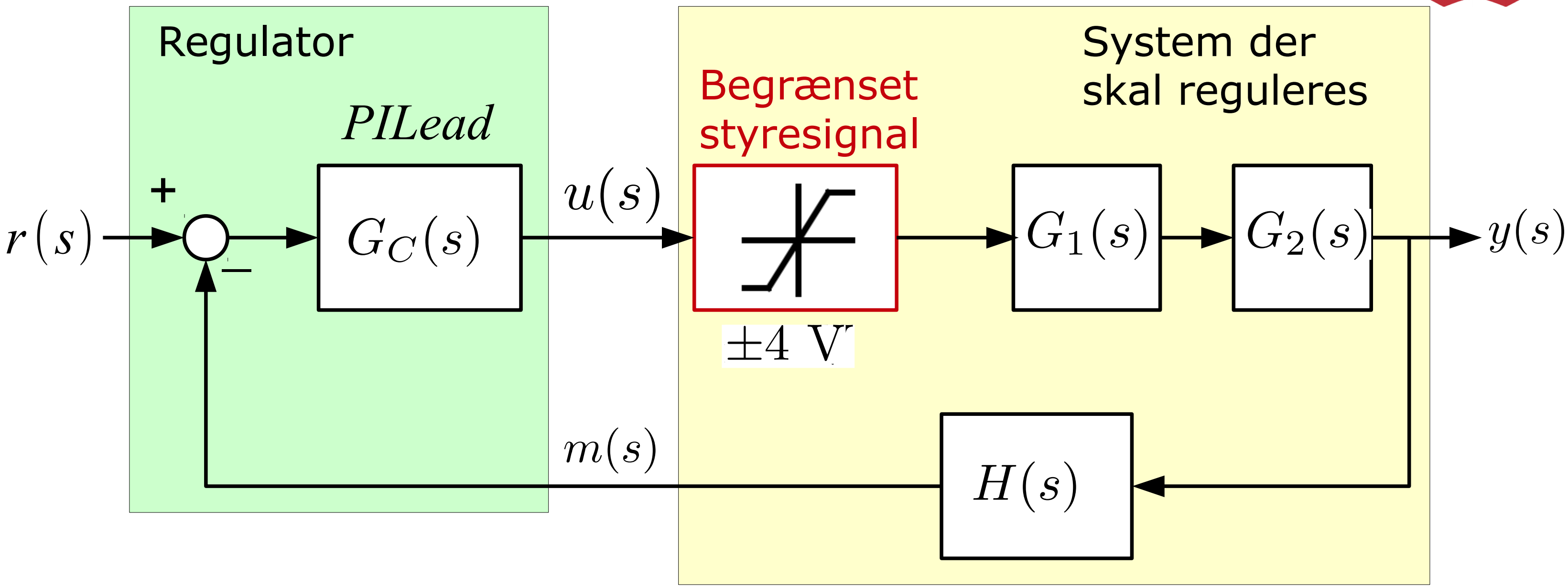
b) Hvordan findes overføringsfunktion for rate-limeted system?
Enten ud fra kendskab til systemet (fx Newtons love),
eller ud fra målinger med så lav amplitude at rate-limiter
er uden betydning.

c) Kan en rate-limited system med et stabilt designet regulator
være ustabil? Ja.

d) Hvordan designes en stabil regulator til et rate-limited system?
F.eks. ved at vælge en (tilstrækkelig) lav krydsfrekvens
så "worst case" input og forstyrrelser ikke gør systemet
ustabilt.

Integrator wind-up

Begrænset styresignal



$$G_1(s) = \frac{178}{0.003s+1}$$

$$G_C(s) = K_P \frac{\tau_d s + 1}{\alpha \tau_d s + 1} \; \frac{\tau_i s + 1}{\tau_i s}$$

$$G_2(s) = \frac{1}{s+1}$$

En langsom pol (eventuelt integrator) sammenlignet med øvrige poler gør problemet større

$$H(s) = \frac{1}{0.0009s+1}$$

Systemet er ikke længere lineært!

Begrænset styresignal Regulator design

$N_i = 5$ $\alpha = 0.1$

$\varphi_i = -11^o$ $\varphi_M = 55^o$

$\gamma_M = 70^o$

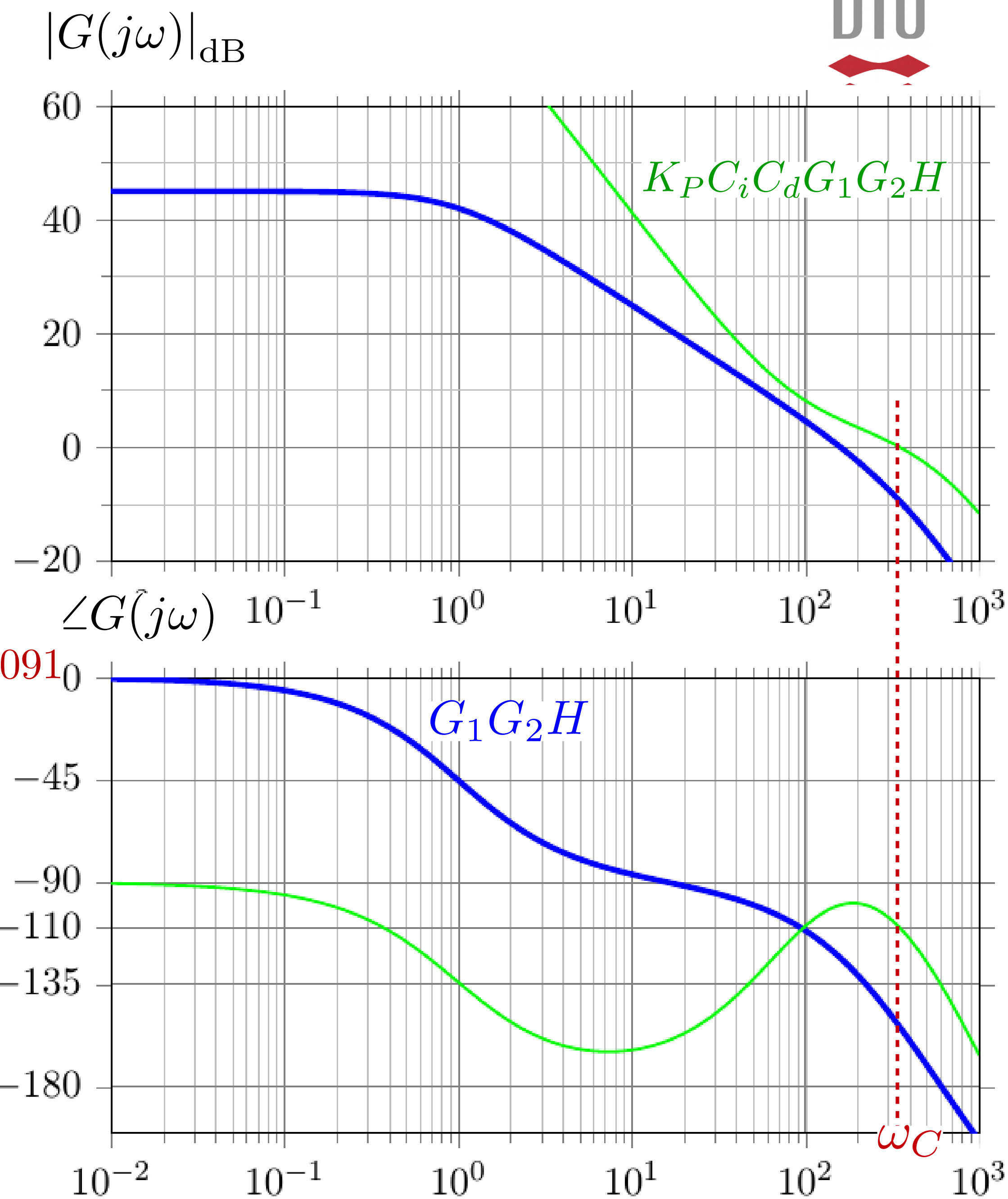
$\angle G(j\omega_C) = -150^o$

$\omega_c = 350 \text{ rad/sek}$

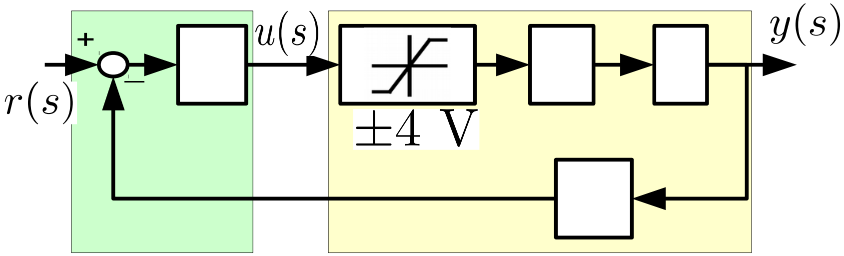
$\tau_i = \frac{N_i}{\omega_c} = 0.014$ $\tau_d = \frac{1}{\omega_c\sqrt{\alpha}} = 0.0091$

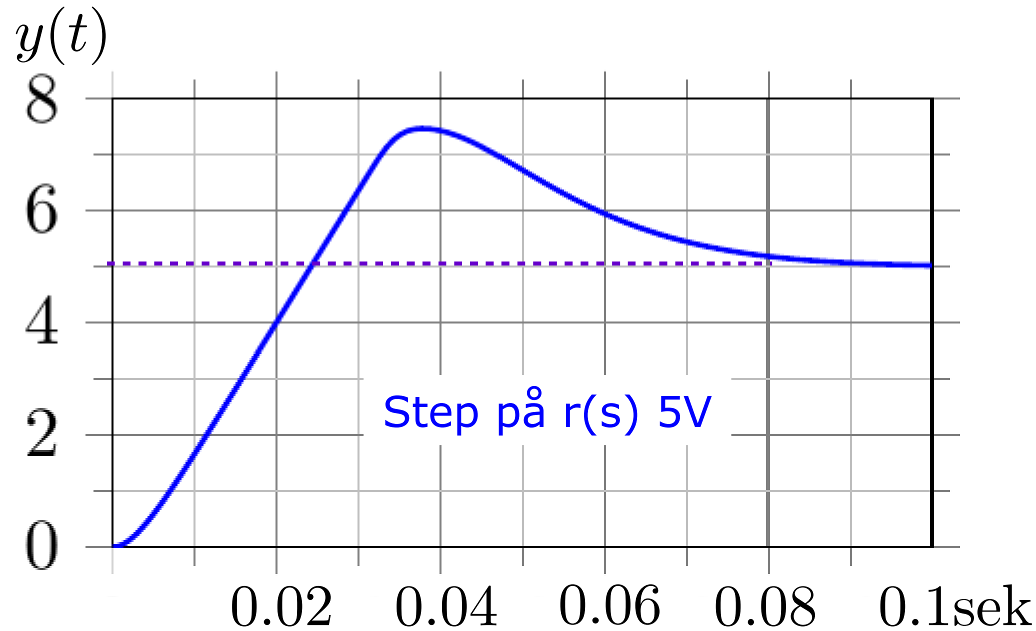
$C_i(s) = \frac{\tau_i s + 1}{\tau_i s}$ $C_d(s) = \frac{\tau_d s + 1}{\alpha\tau_d s + 1}$

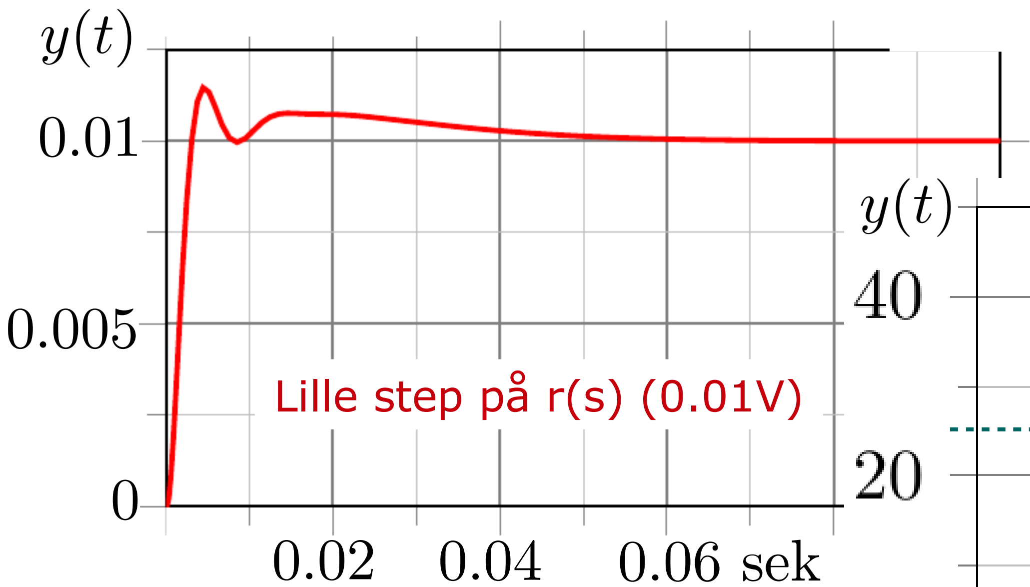
$K_P = 0.92$

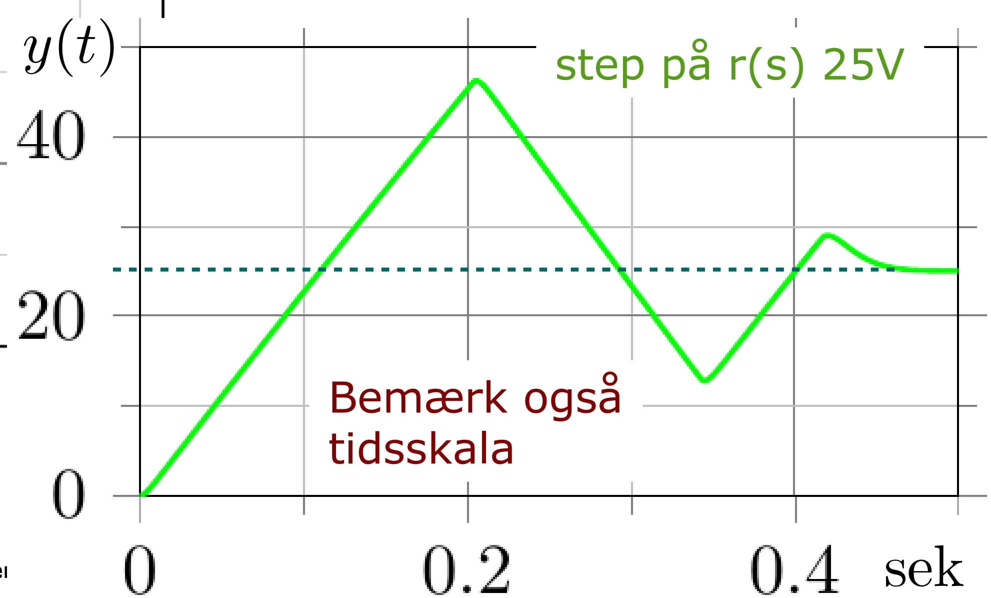


Effekt af begænser
Step responce

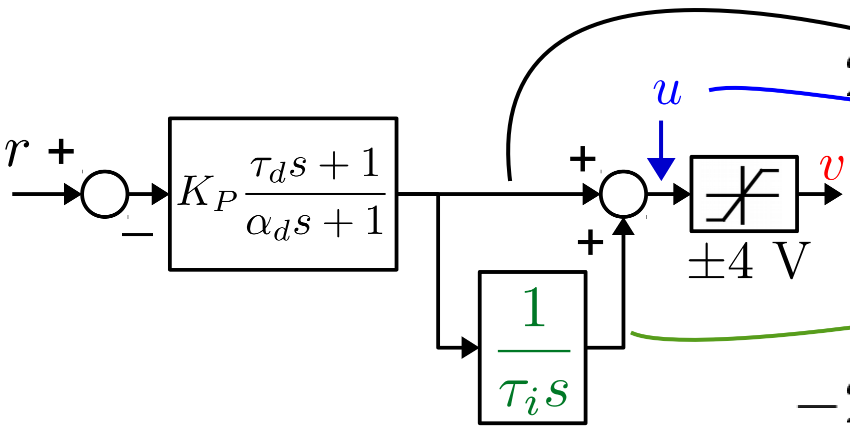


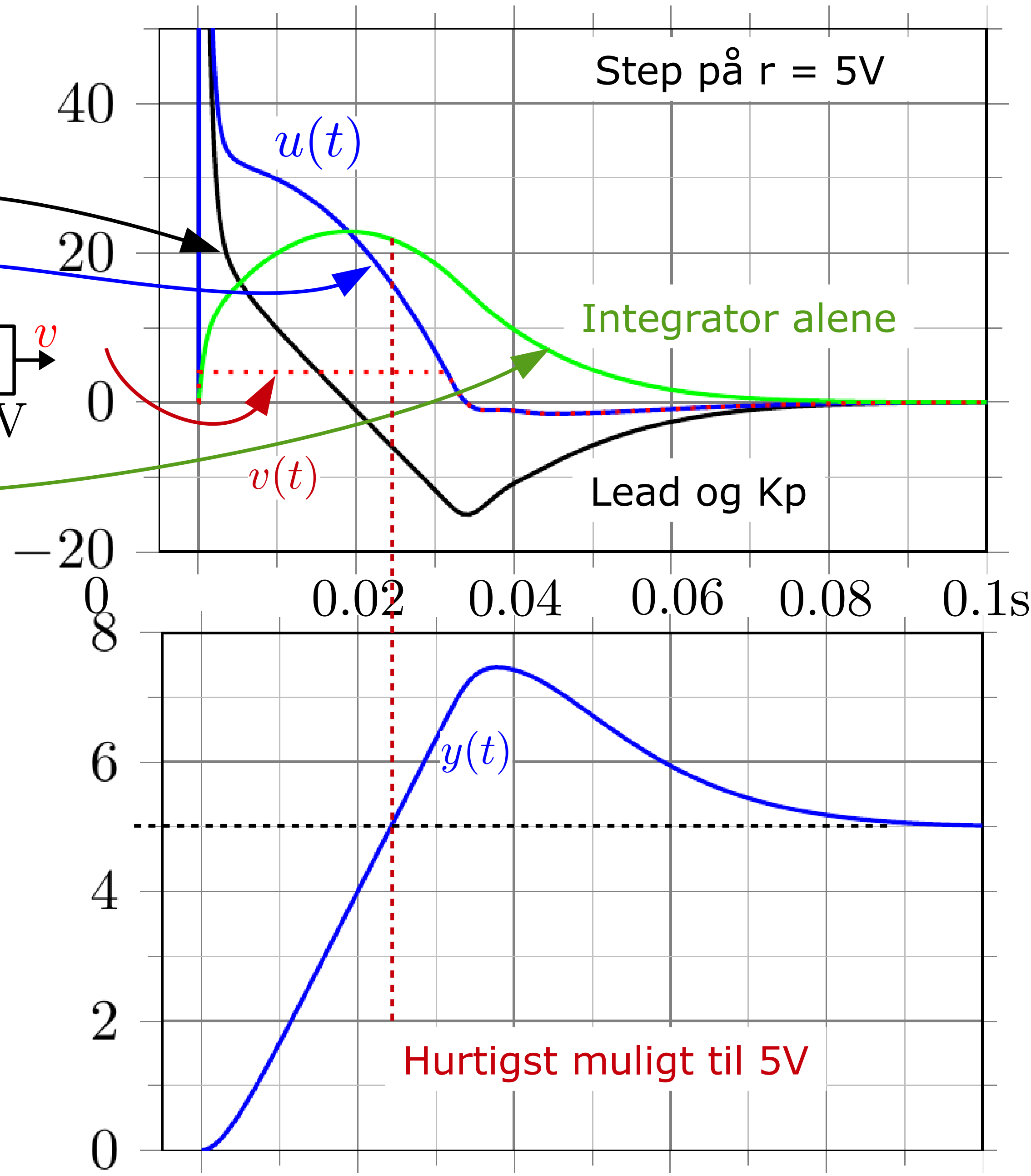






Begrænset styresignal





$$r(s) = \frac{5}{s}$$

Problem:
Integrator wind-up

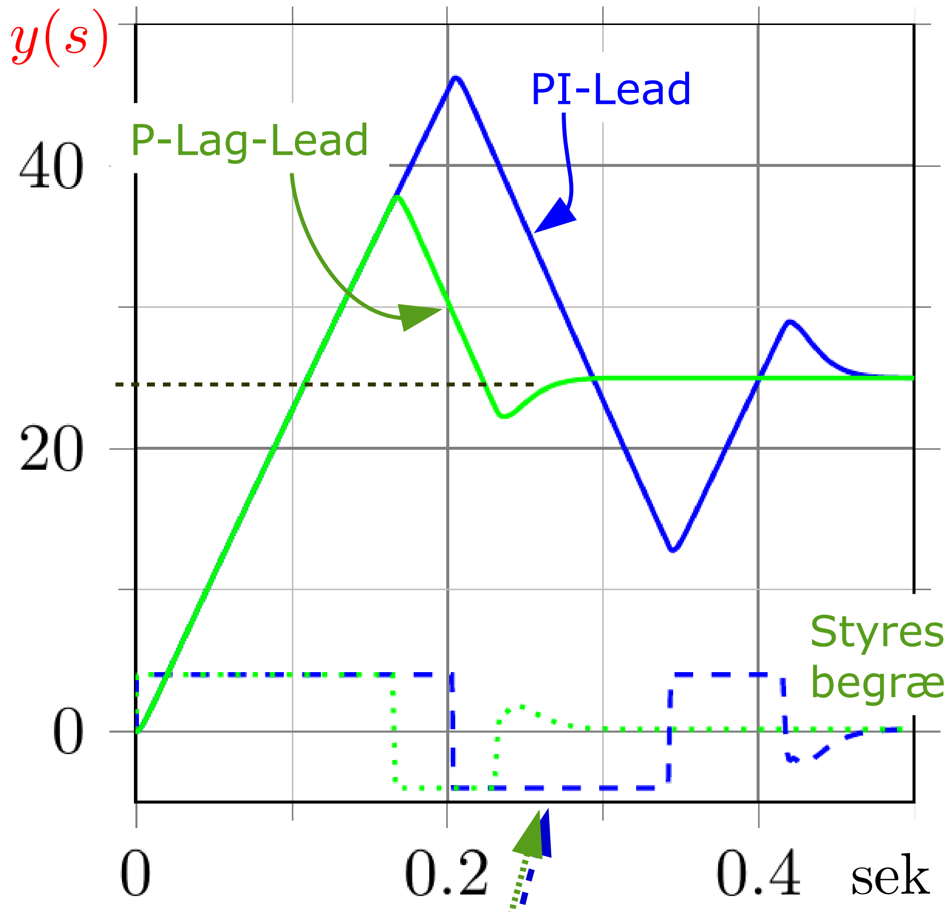
Begrænset styresignal Lag-led

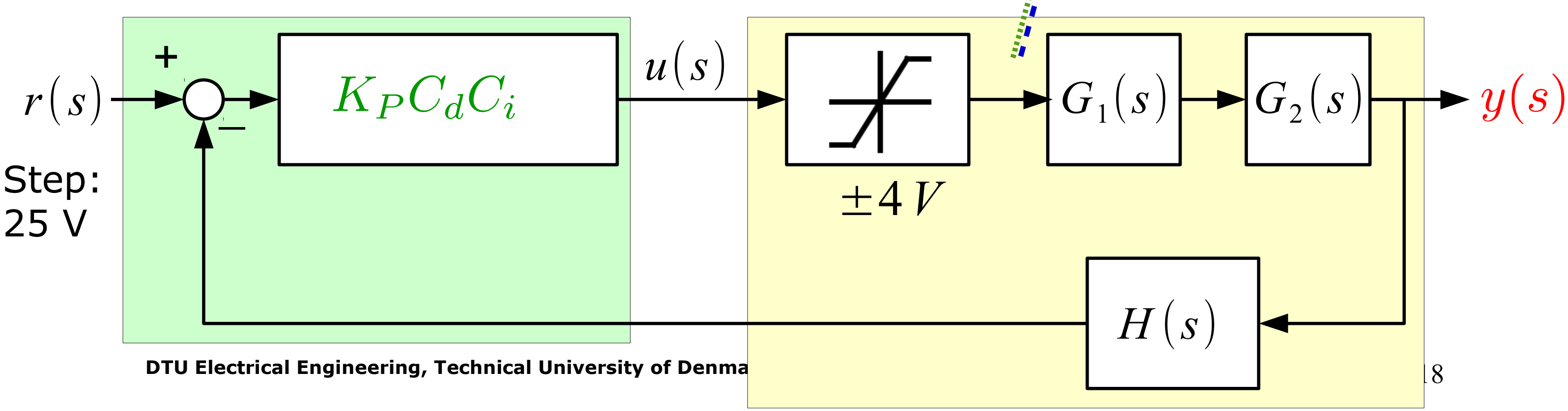
Høj gain er godt for statisk fejl, I-led eller kun Lag

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

$$C_i = \frac{\tau_i s + 1}{\tau_i s + 1/\beta}$$

$\beta = 10 \Rightarrow$ faktor 10 mindre stationær fejl (ift. uden I-led)





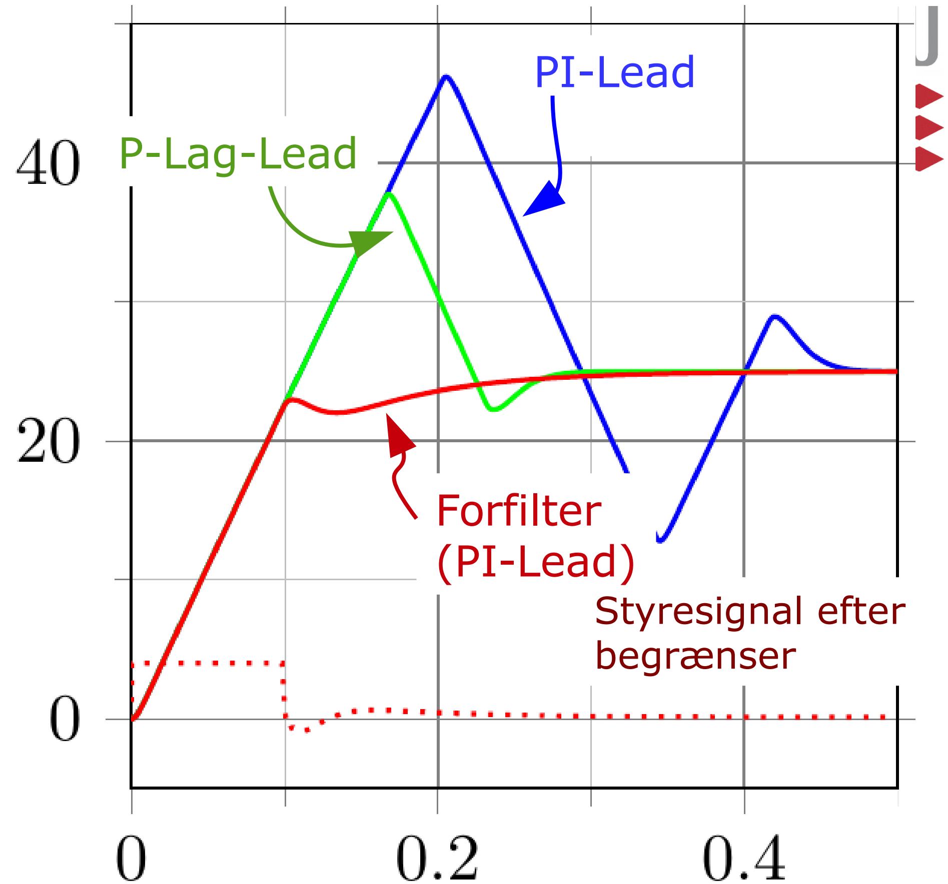
Begrænset styresignal Forfilter

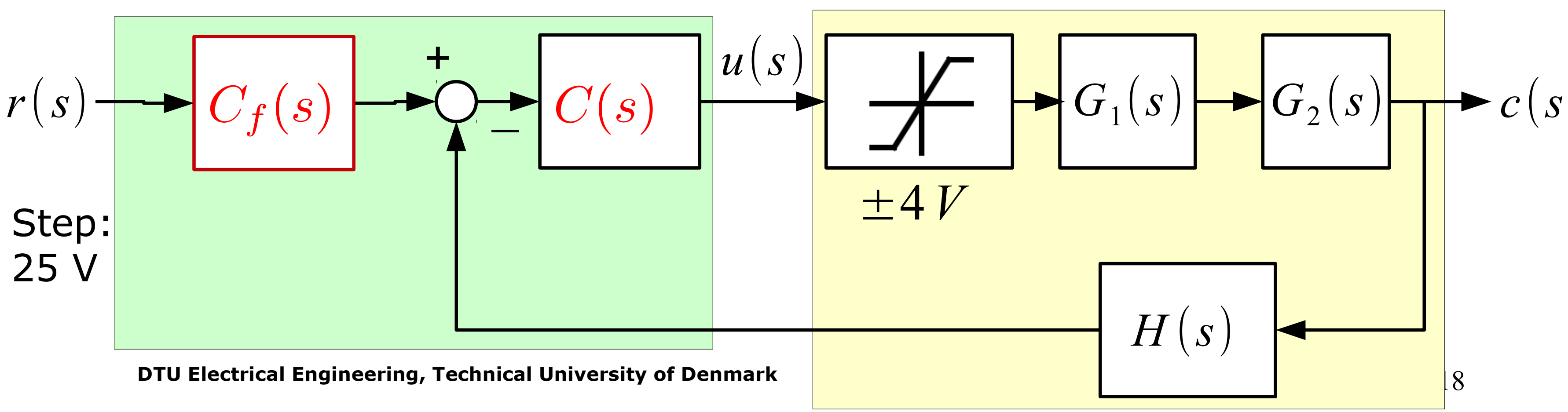
$$C_f(s) = \frac{1}{\tau_f s + 1}$$

τ_f er valgt, ud fra typisk indsvingningstid, her er valgt:

$$\tau_f = 0.07 \text{ sek}$$

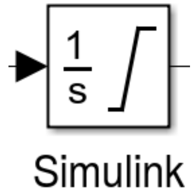
Indsvingning bliver langsommere, ved små signaler (hvor indsvingning før var 0.005 sek!)

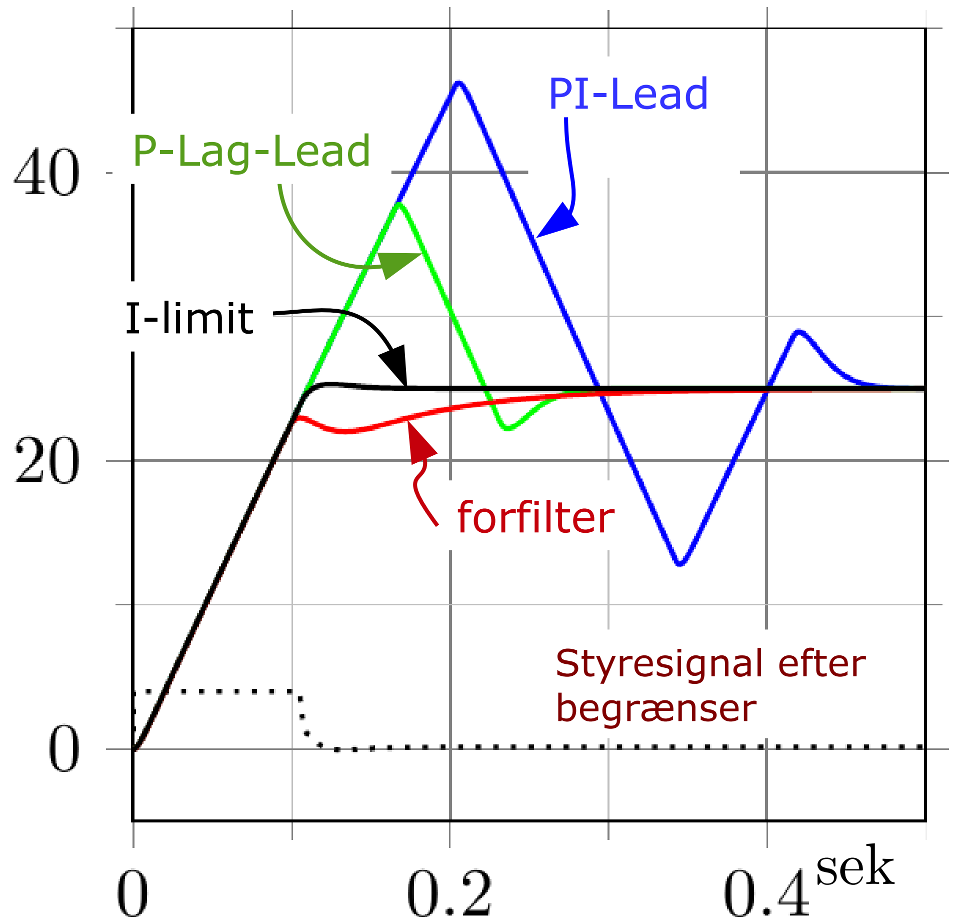




Step: 25 V

Begrænset integrator

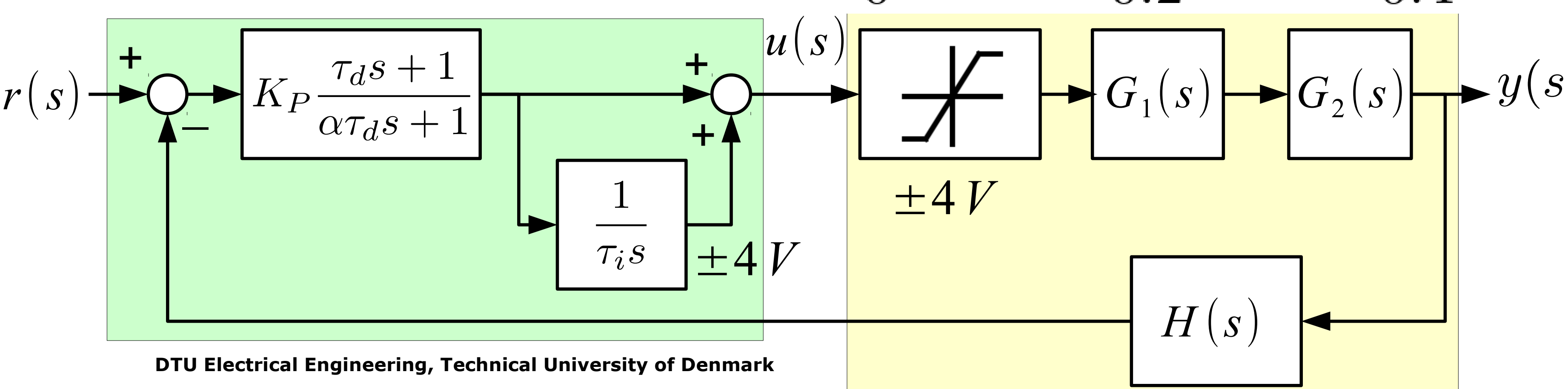




Separat I-led med begrænser

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

I-led begrænsning kan ofte være det bedste valg

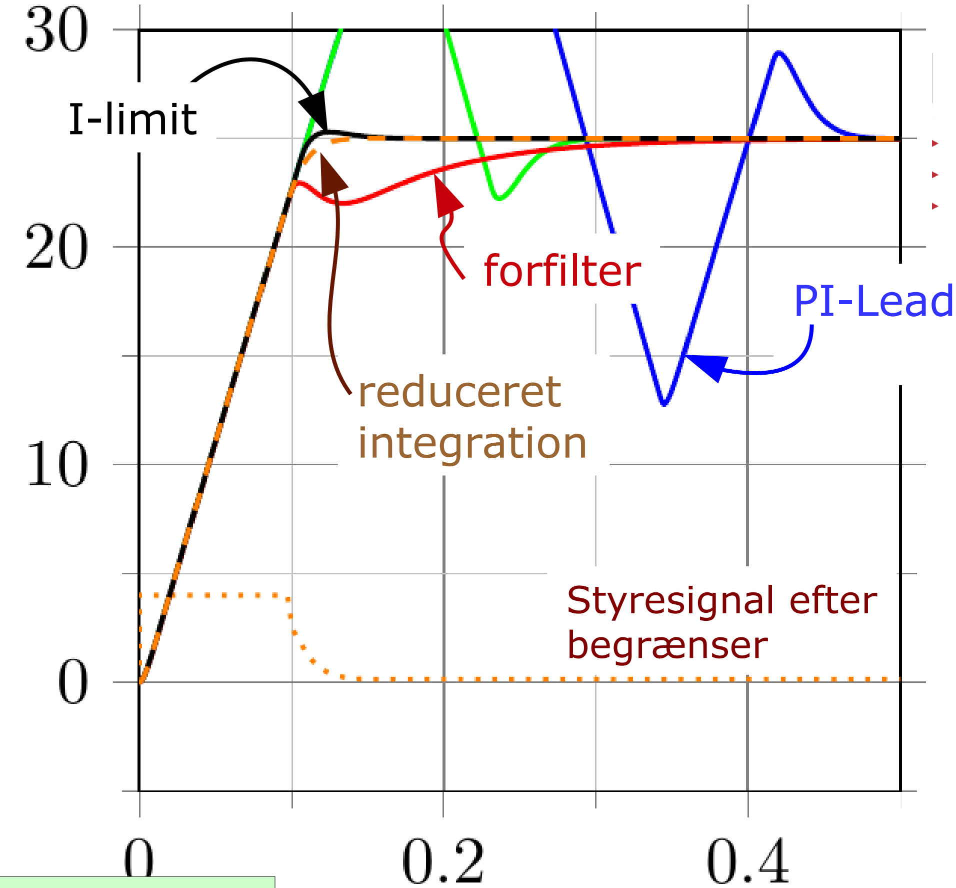


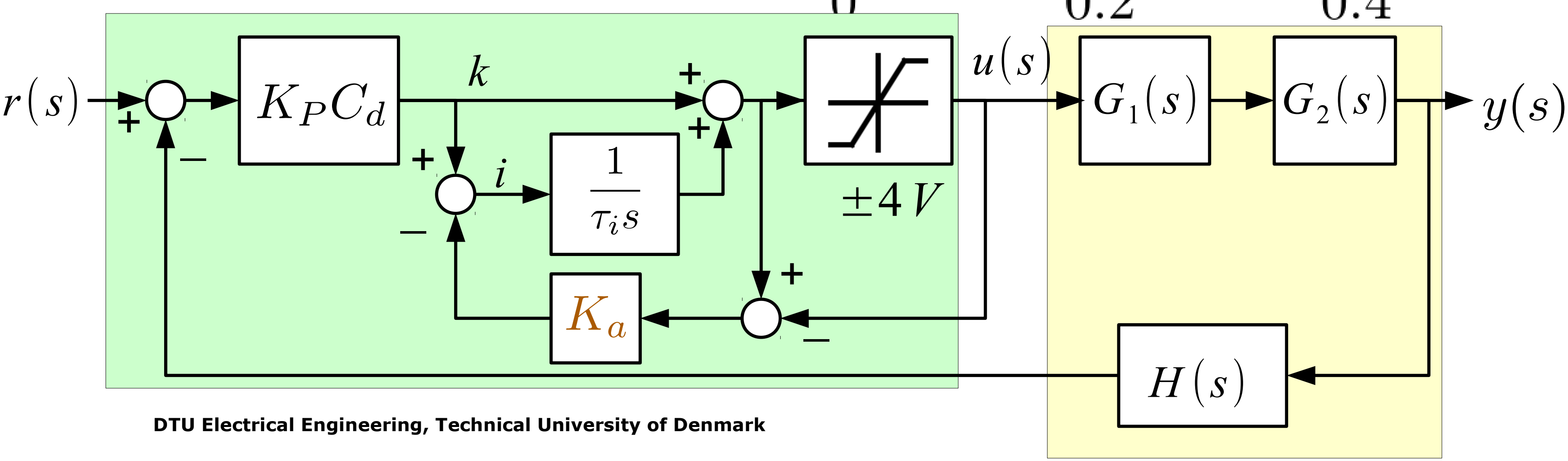
Integrator reduktion

Ved begrænsning reduceres integration

I-led input reduceres med lige så meget som u er begrænset, med en faktor her: $K_a = 2$

(Alternativt kan input til integrator stoppes ved begrænsning)





fremover

- Plan for resten af kurset (lektion og *øvelse*)
  - 10 Ustabile systemer (*REGBOT balance*)
  - 11 Forstyrrelser, støj, sensitivitet (*REGBOT balance*)
  - 12 Feed forward, delay (*REGBOT balance – youtube?*)
  - 13 Prøveeksamen, digital regulator (*REGBOT rapport*)