

# A new method to deal with the saturation problem in feedforward control for measurable disturbances

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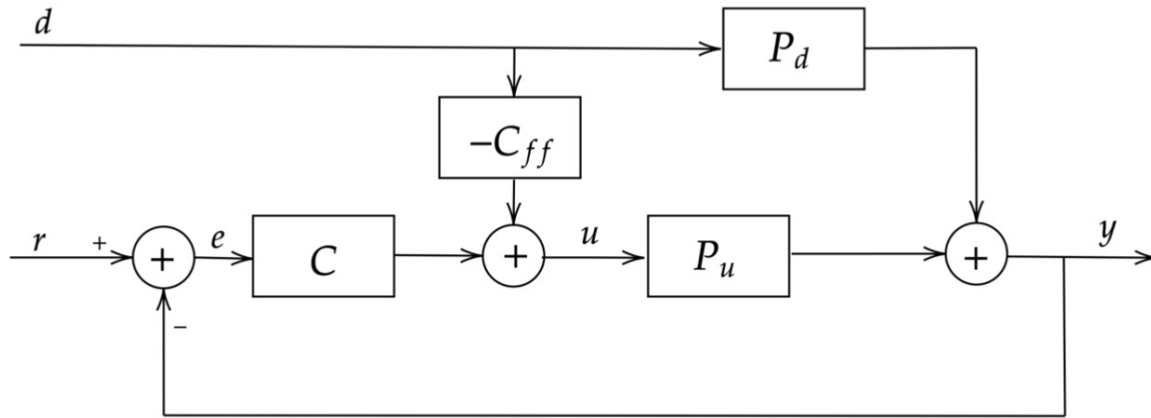
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Tore Hägglund

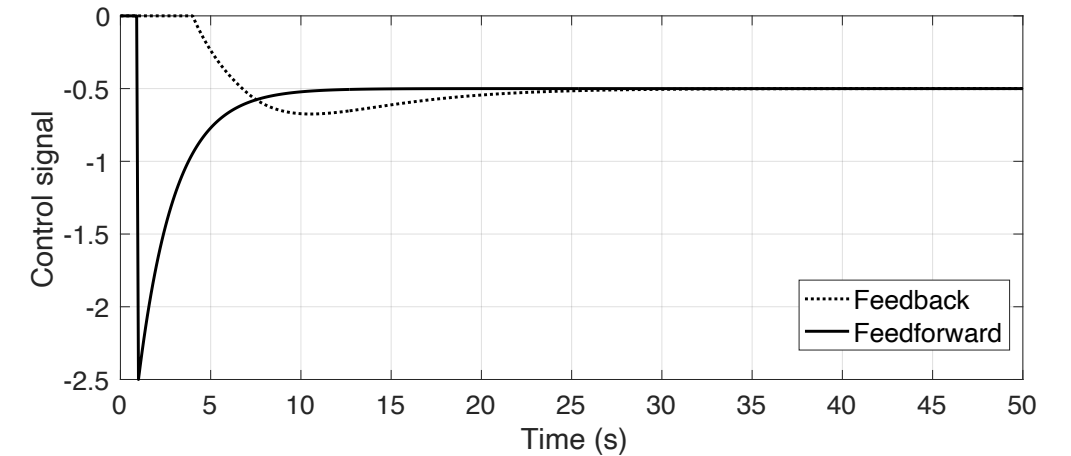
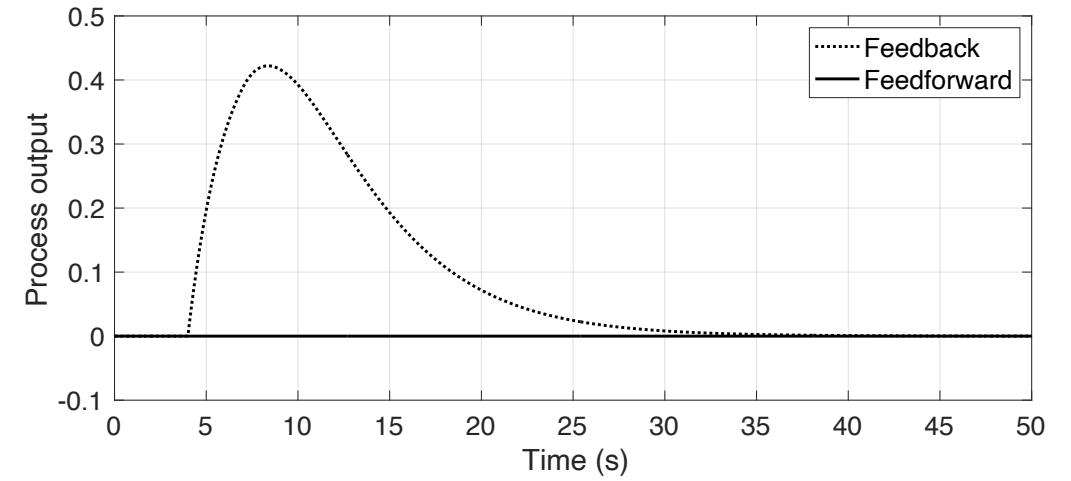
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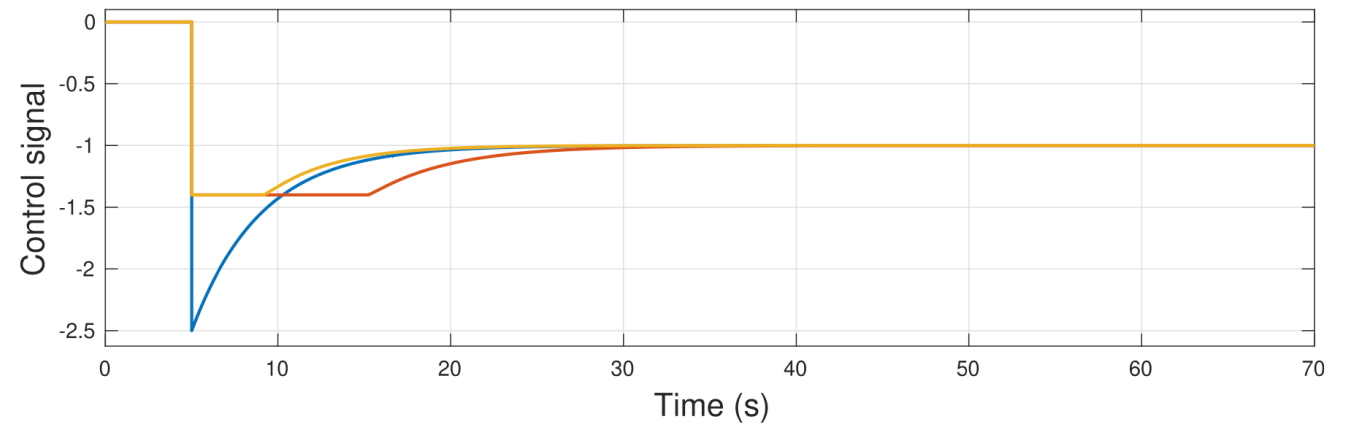
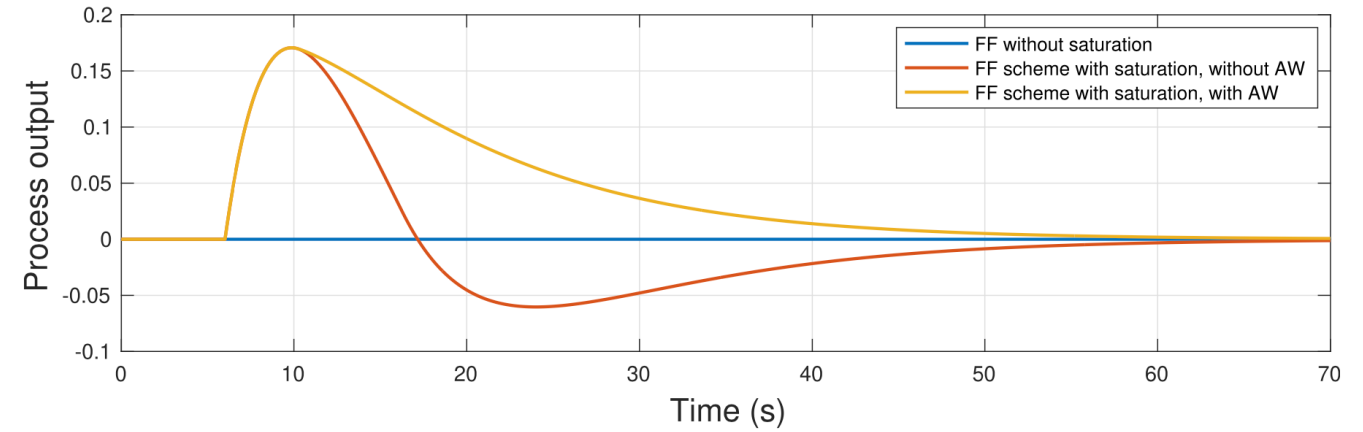
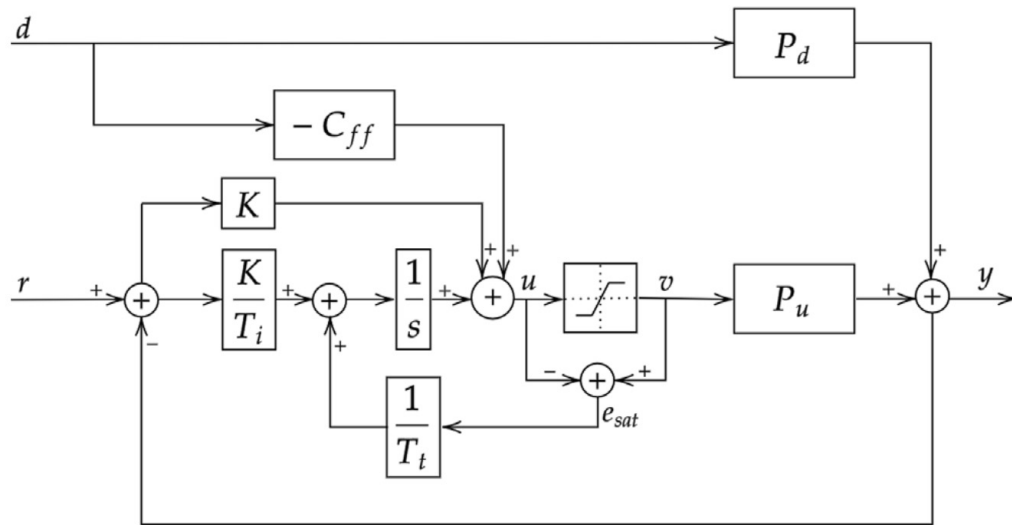
$$C_{ff} = \frac{P_d}{P_u}$$



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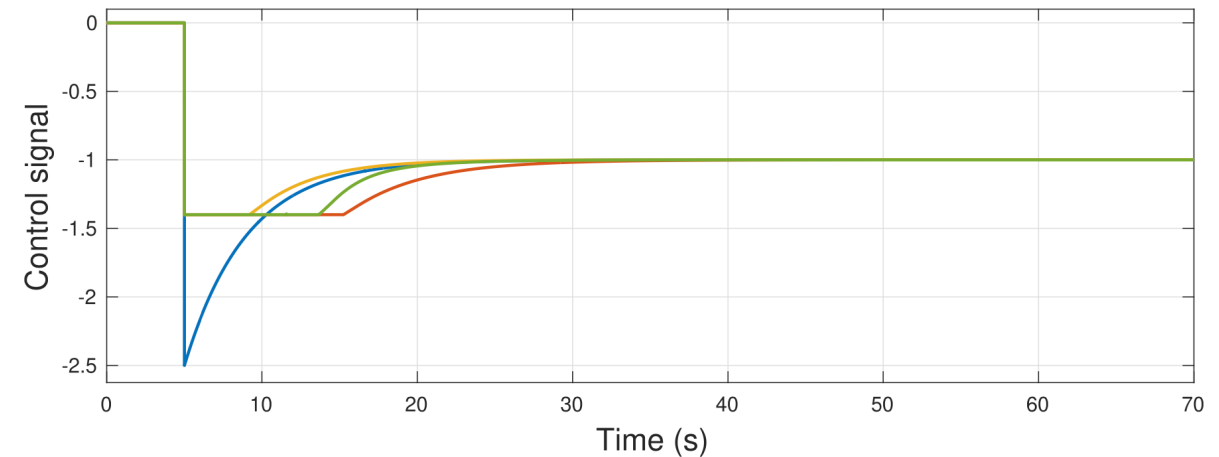
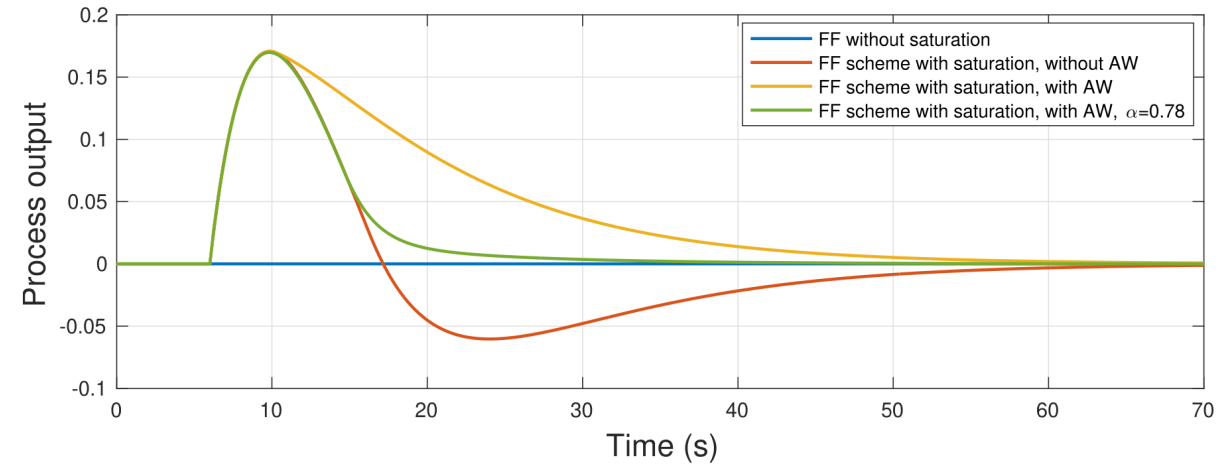
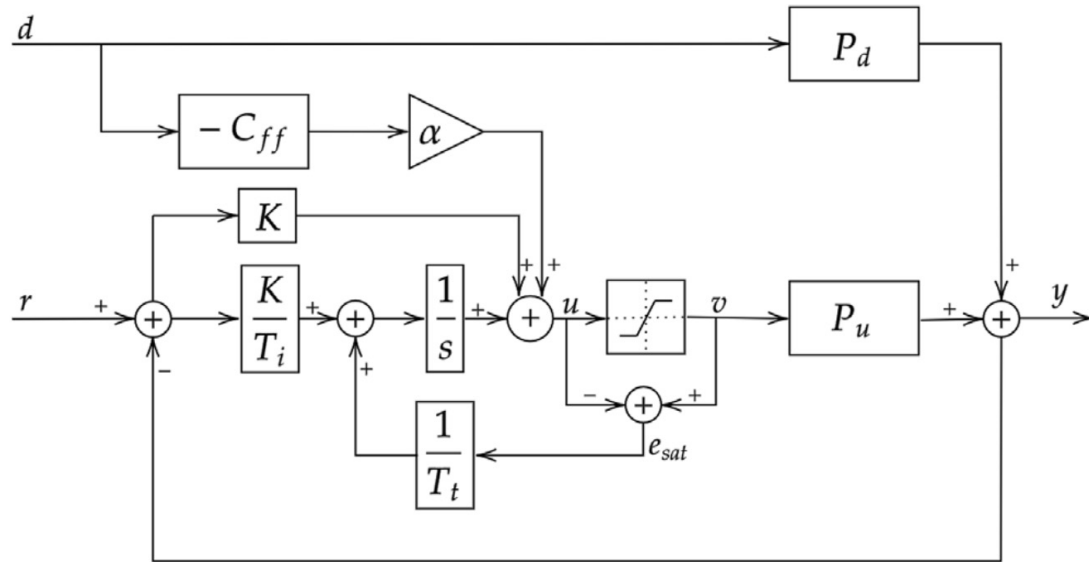
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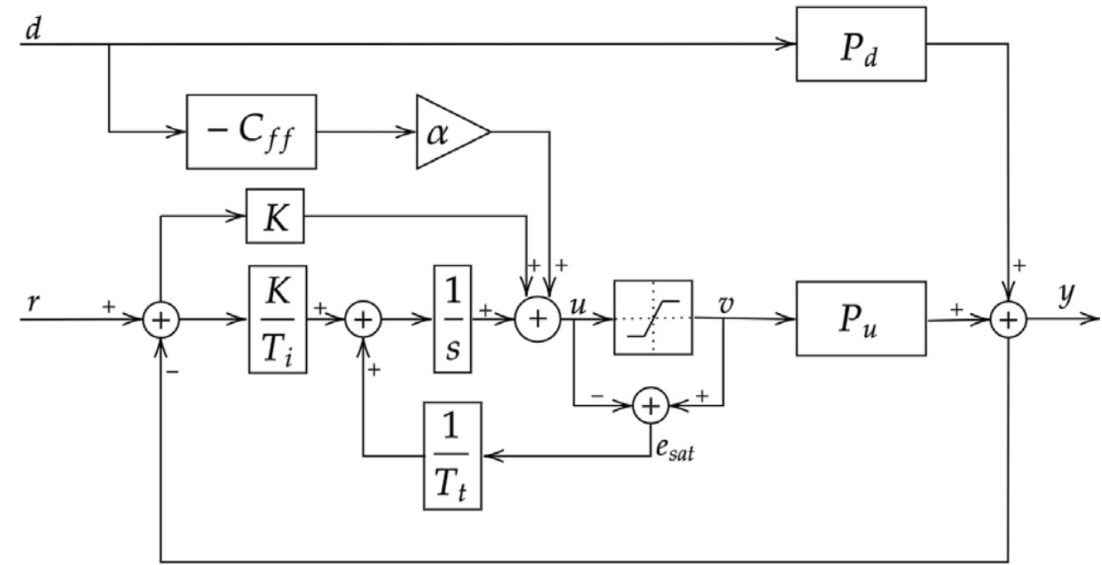
# 1

## Preliminaries

$$P_u = \frac{K_u}{1 + sT_u} e^{-sL_u} \quad P_d = \frac{K_d}{1 + sT_d} e^{-sL_d}$$

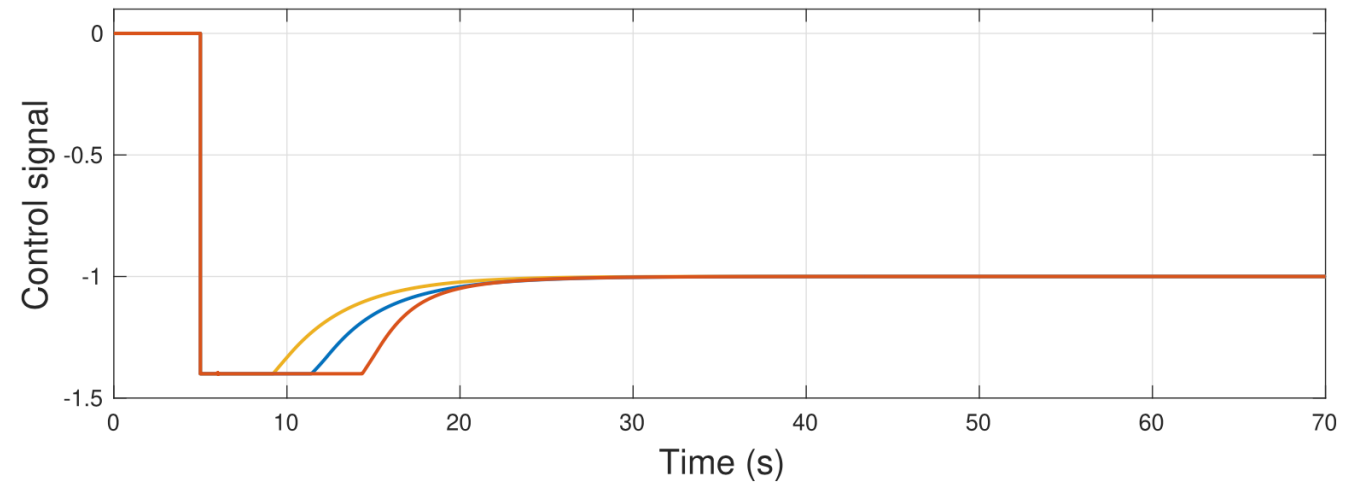
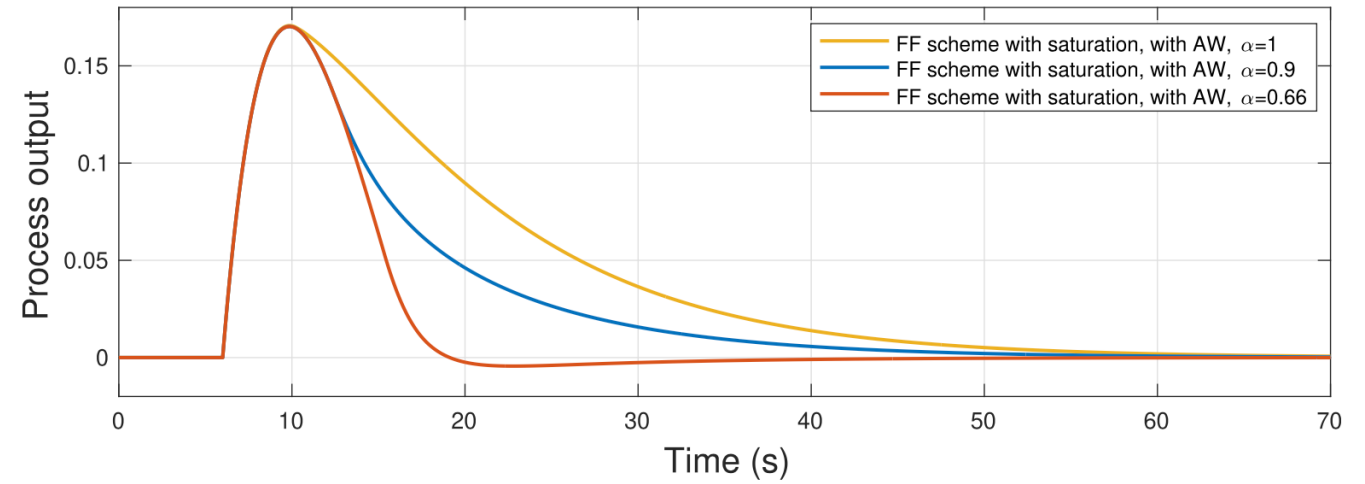
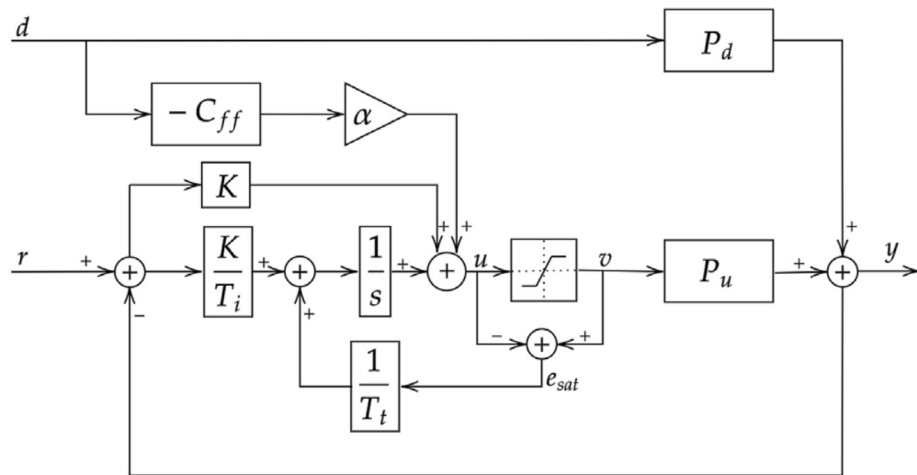
$$C = K \left( 1 + \frac{1}{sT_i} \right) \quad K = \frac{T_u}{K_u(\lambda + L_u)}, \quad \tau_i = T_u$$

$$C_{ff} = \frac{P_d}{P_u} \quad C_{ff} = \frac{K_d sT_u + 1}{K_u sT_d + 1} e^{-s(L_d - L_u)}$$



# 2 Proposed method

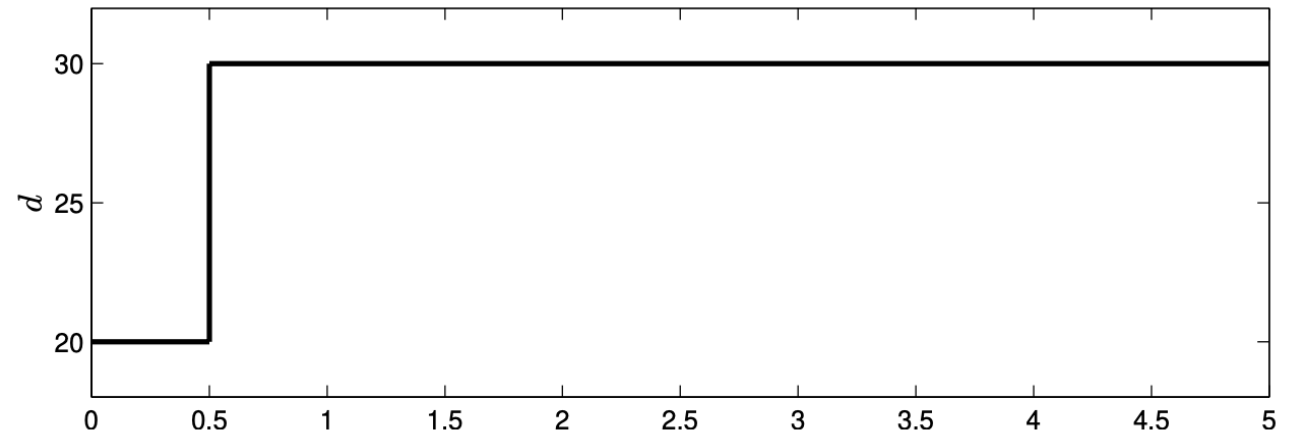
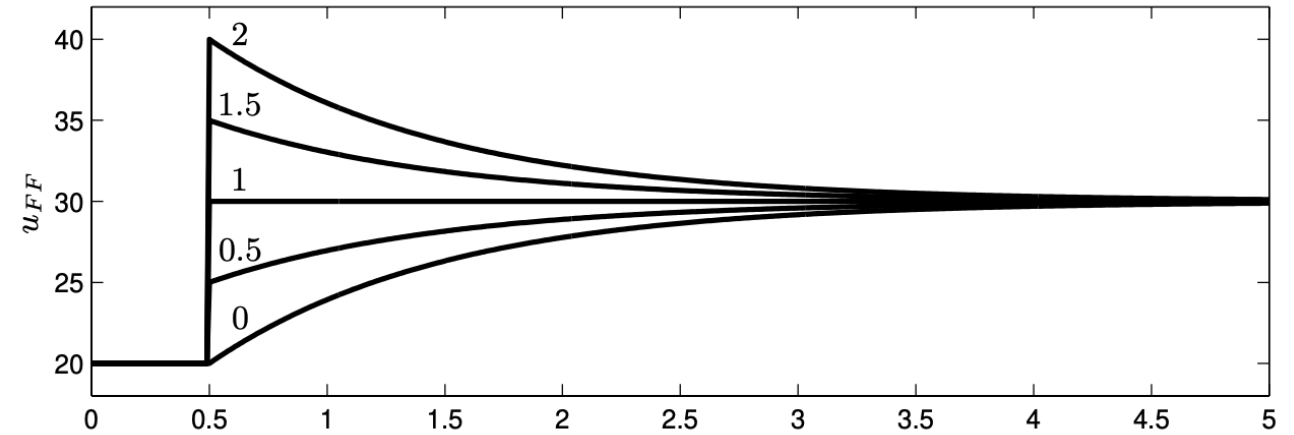
# Proposed method





$$C_{ff} = K_{ff} \frac{sT_z + 1}{sT_p + 1} \cdot e^{-sL_{ff}}$$

$$T_z > T_p$$

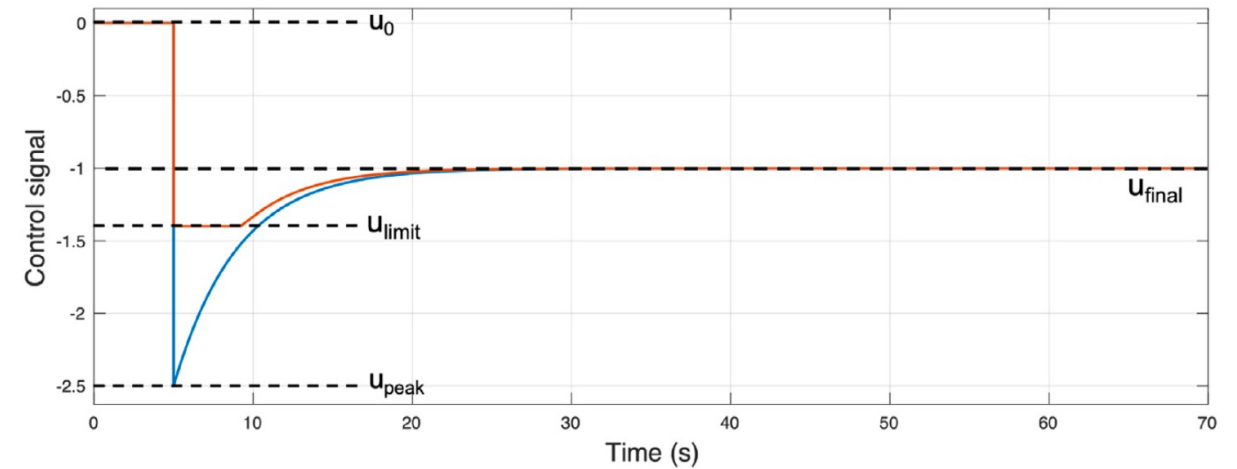
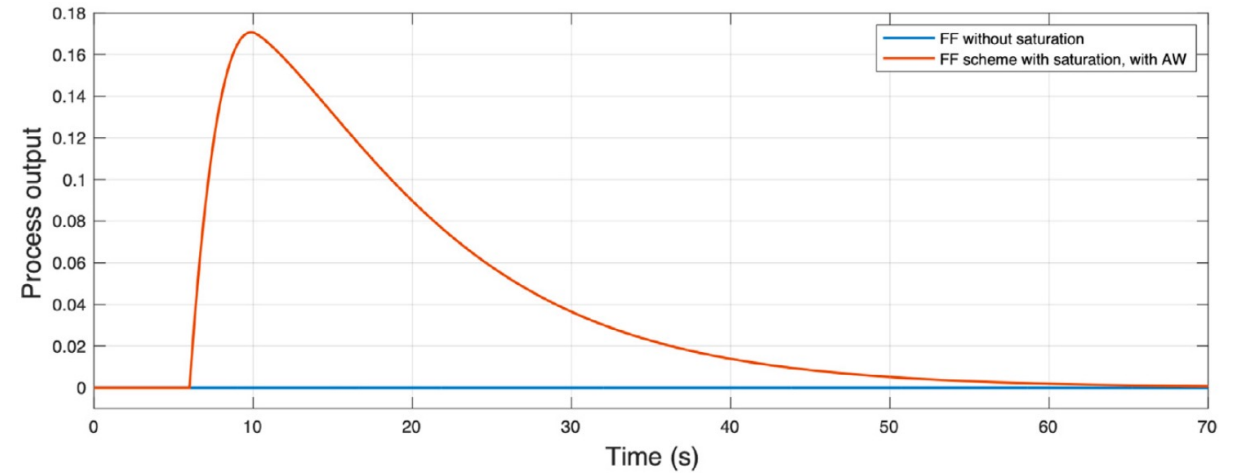


$$u_{peak} = \lim_{t \rightarrow 0} u(t) = \lim_{s \rightarrow \infty} -s C_{ff}(s) \frac{d}{s} = \lim_{s \rightarrow \infty} -s \frac{K_d T_u s + 1}{K_u T_d s + 1} \frac{d}{s} = -K_{ff} \frac{T_u}{T_d} d$$

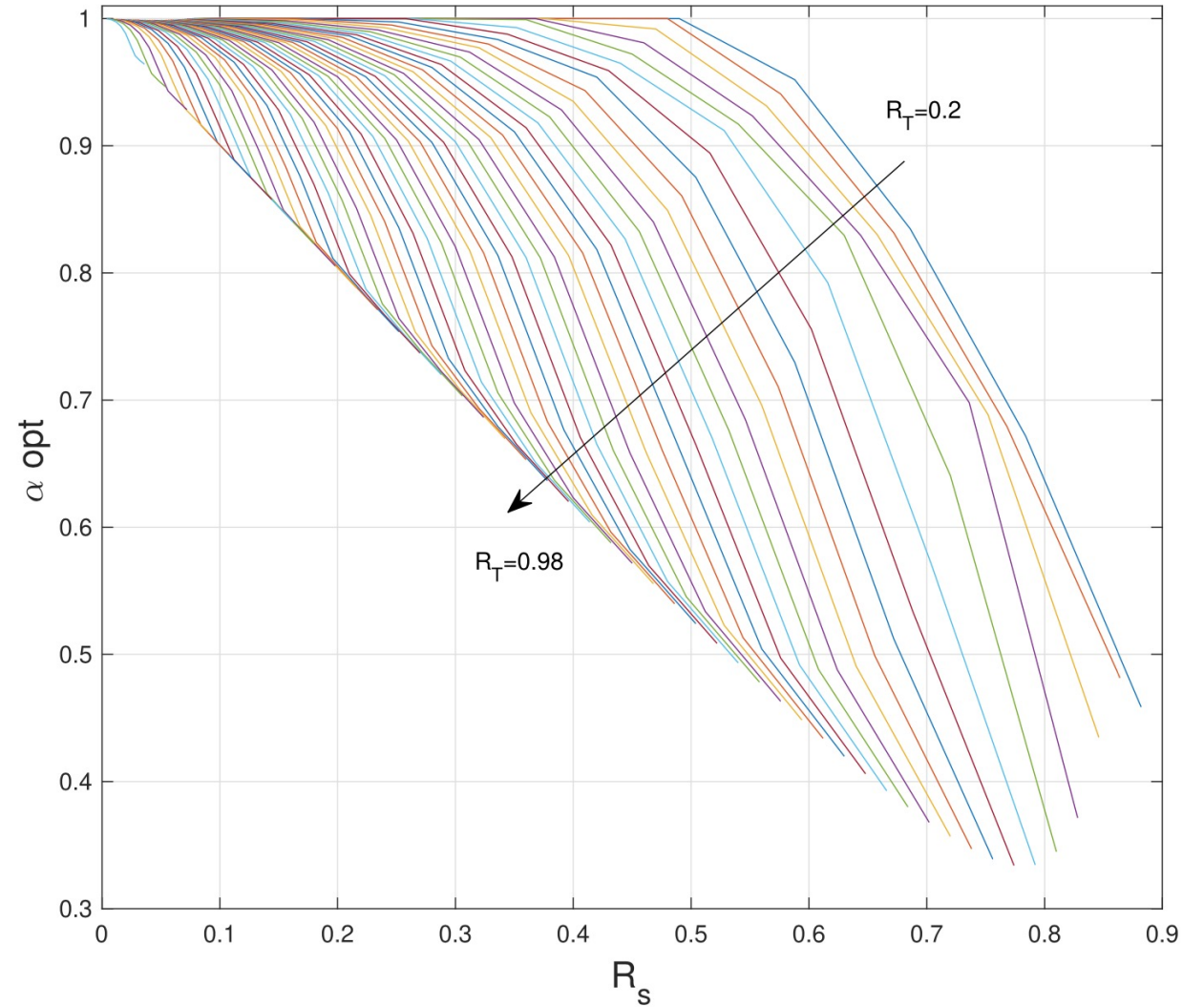
$$u_{final} = \lim_{t \rightarrow \infty} u(t) = \lim_{s \rightarrow 0} -s C_{ff}(s) \frac{d}{s} = \lim_{s \rightarrow 0} -s \frac{K_d T_u s + 1}{K_u T_d s + 1} \frac{d}{s} = -K_{ff} d$$

$$R_T = \frac{T_p}{T_z} \quad \text{where : } R_T \in (0, 1)$$

$$R_S = \frac{u_{peak} - u_{limit}}{u_{peak} - u_0} \quad \text{where : } R_S \in (0, 1)$$

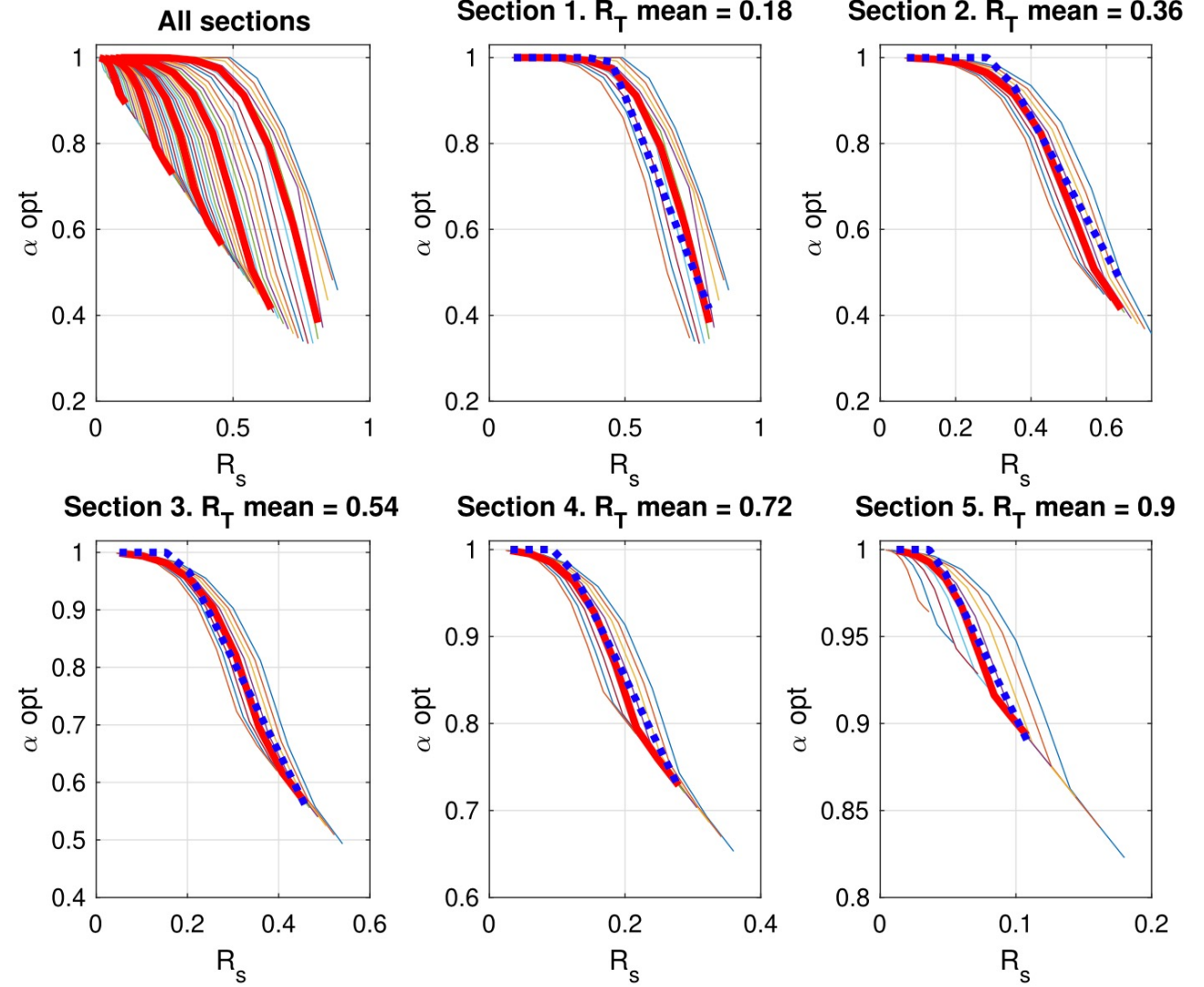


$$\min_{\alpha} \int_0^{T^*} |e(t)| dt \quad \text{such that : } 0 < \alpha \leq 1$$

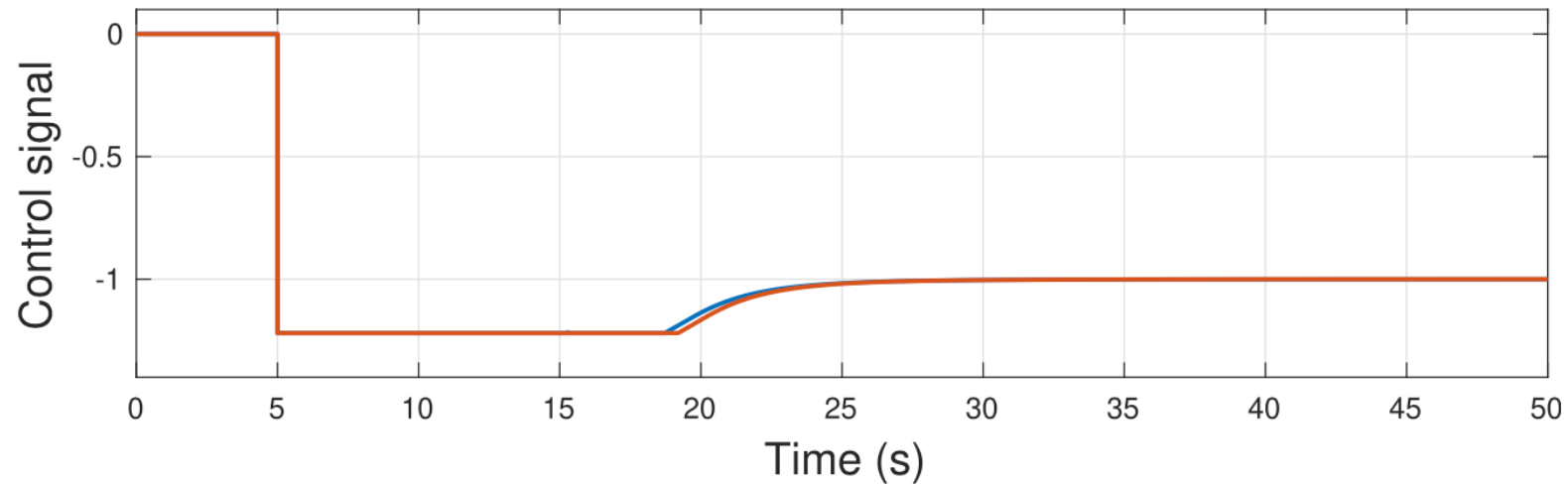
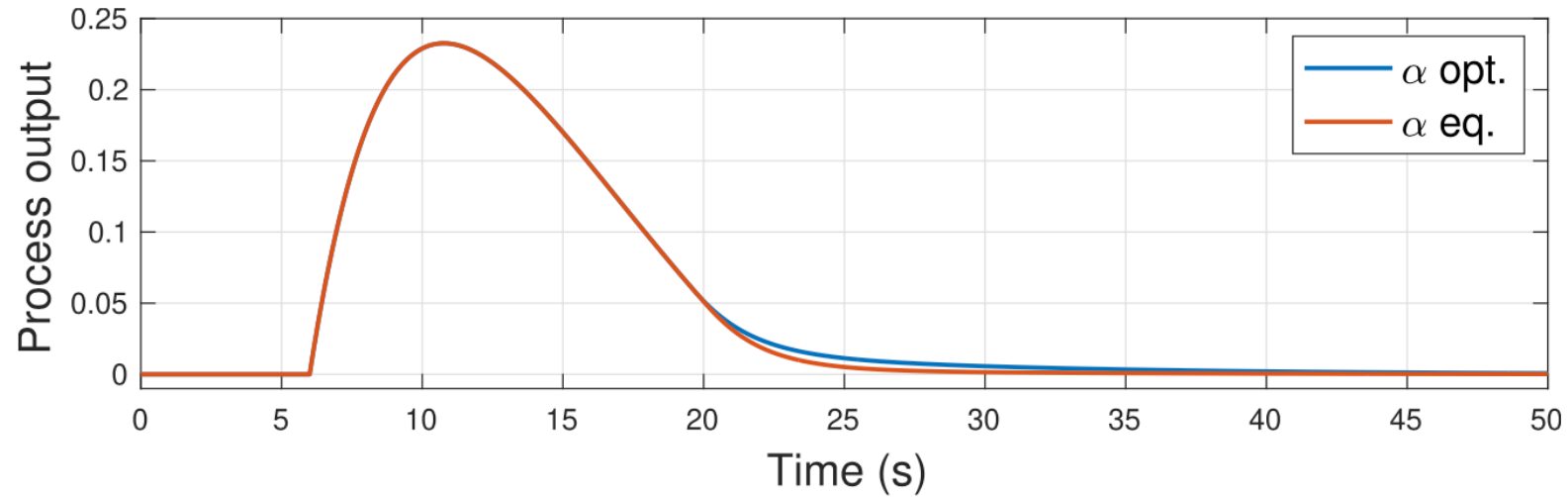


$$\alpha = \begin{cases} f & 0 < f < 1 \\ 1 & \text{else} \end{cases}$$

$$f(R_S, R_T) = -1.6 \cdot R_S - R_T + 1.9$$



# Proposed method



# 3 Examples

**Example 1.**  $K_u = K_d$ ,  $L_u = L_d$ , small  $R_T$  and large  $R_S$ .

**Example 2.**  $K_u \neq K_d$ ,  $L_u = L_d$ , small  $R_T$  and medium  $R_S$ .

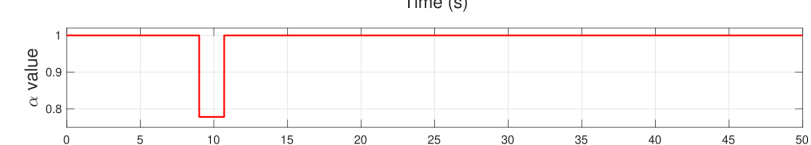
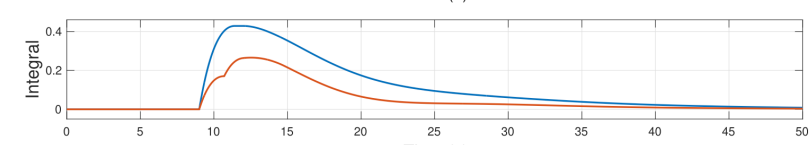
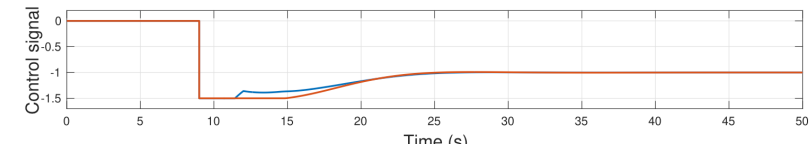
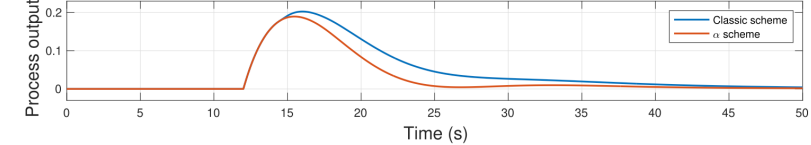
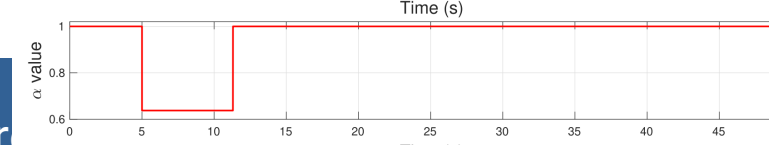
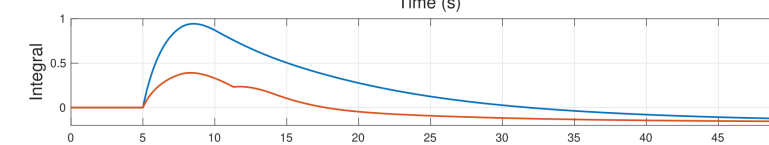
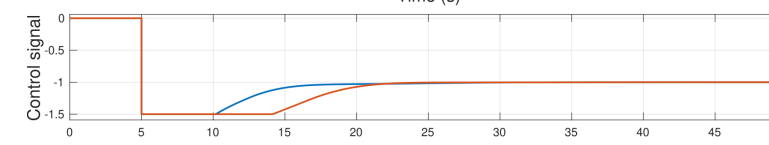
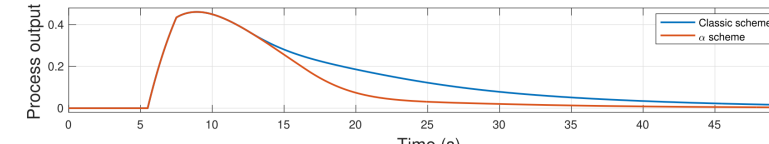
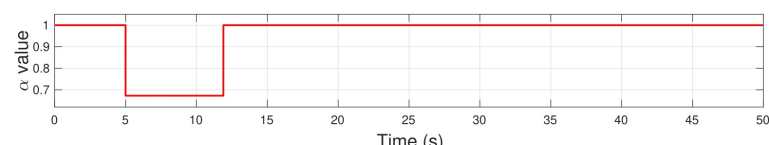
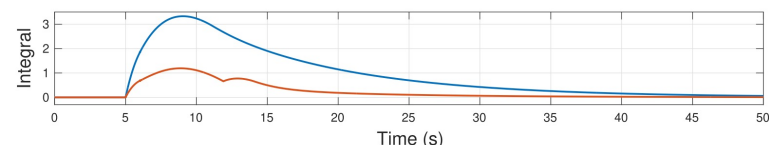
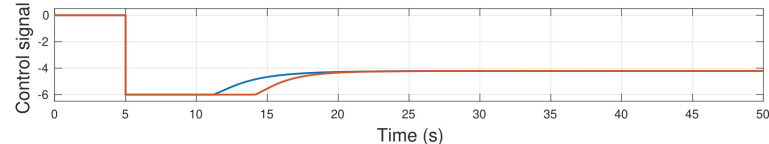
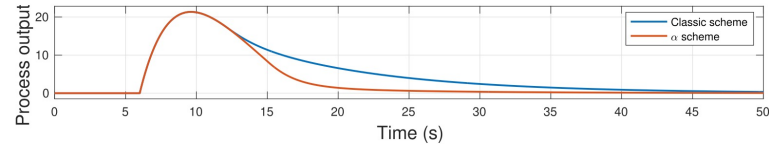
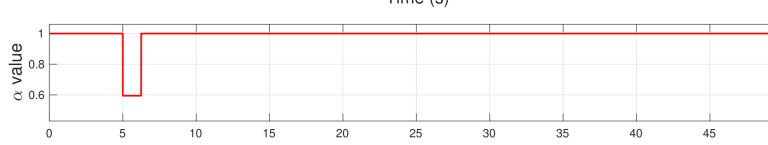
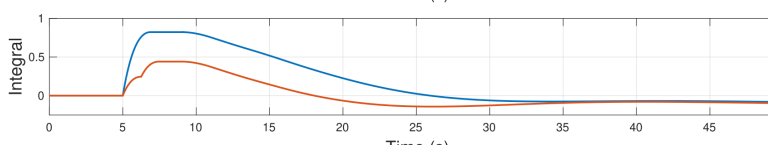
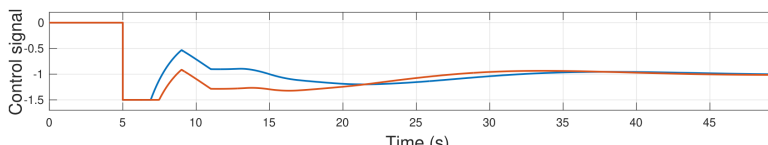
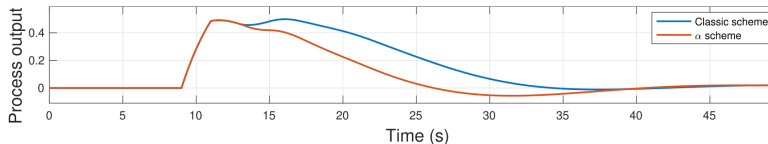
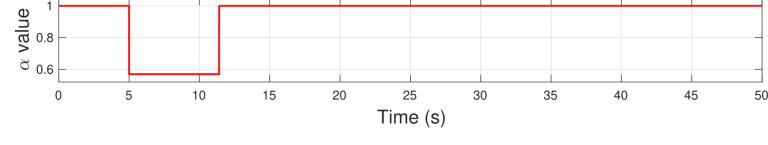
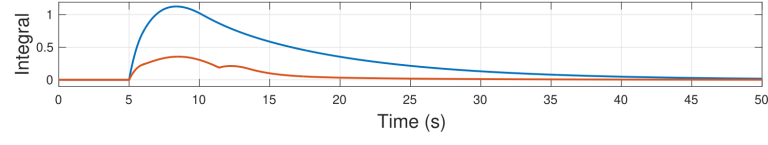
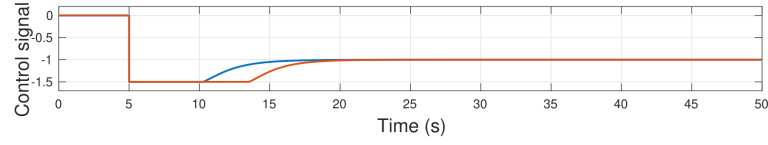
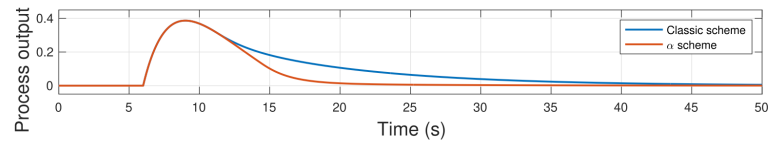
**Example 3.**  $K_u = K_d$ ,  $L_u < L_d$  (no inversion problem), small  $R_T$  and medium  $R_S$ .

**Example 4.**  $K_u = K_d$ ,  $L_u > L_d$  (inversion problem), small  $R_T$  and medium  $R_S$ .

**Example 5.**  $K_u = K_d$ ,  $L_u = L_d$ , small  $R_T$  and medium  $R_S$ .  $P_1$  and  $P_2$  are second-order transfers function with two real poles.



# Examples



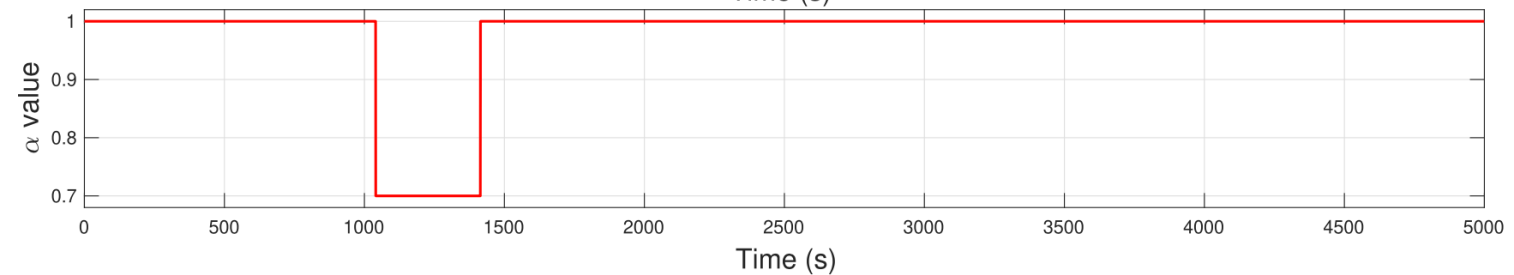
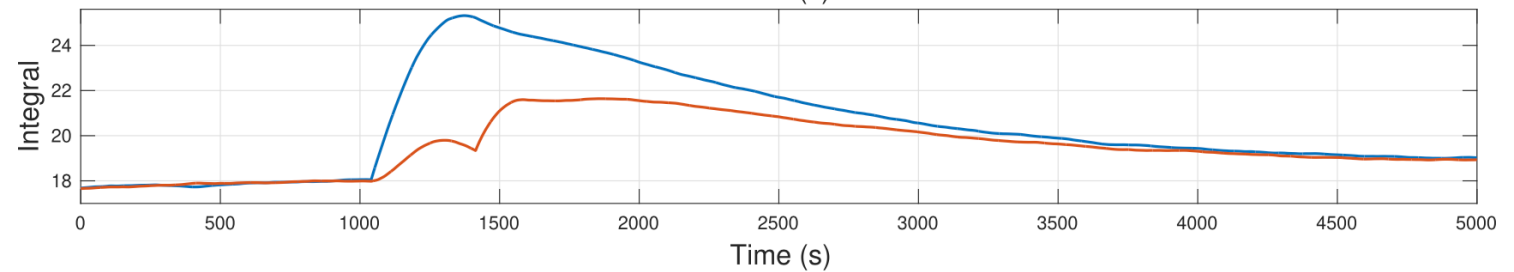
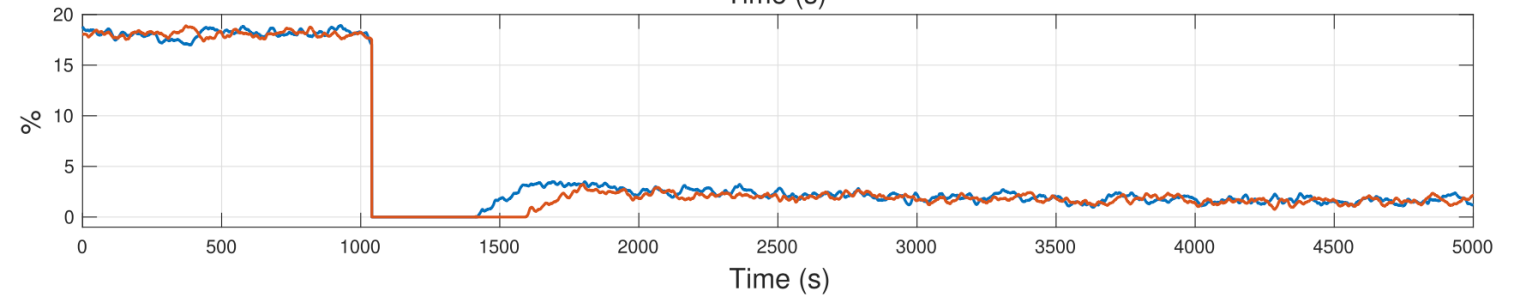
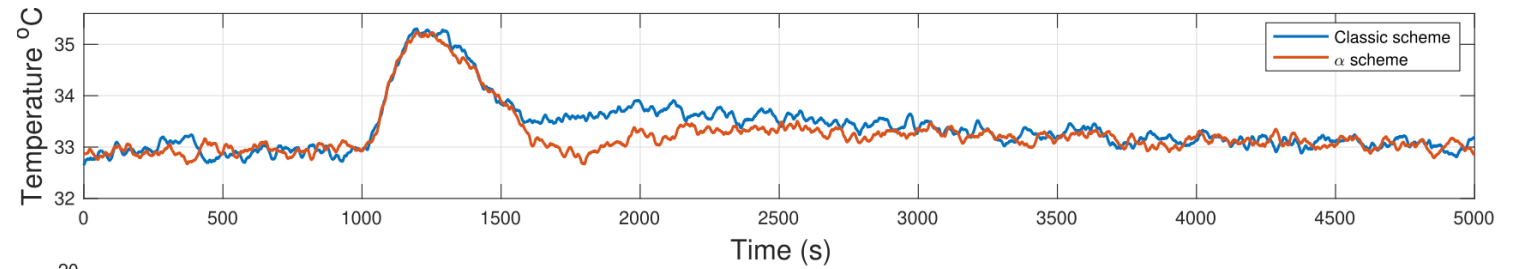
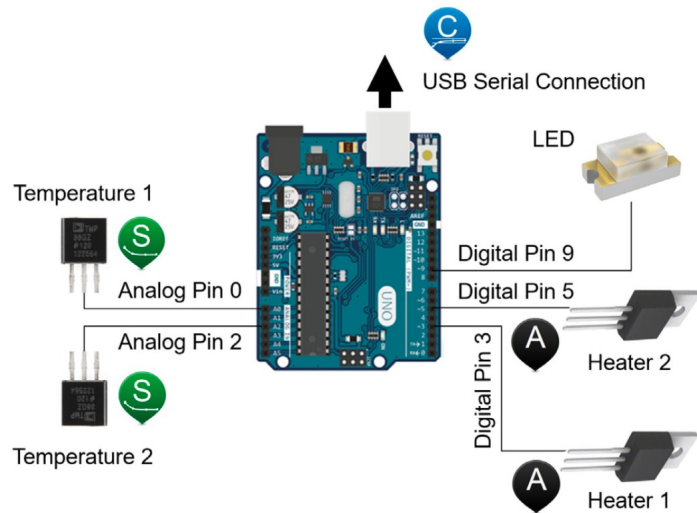
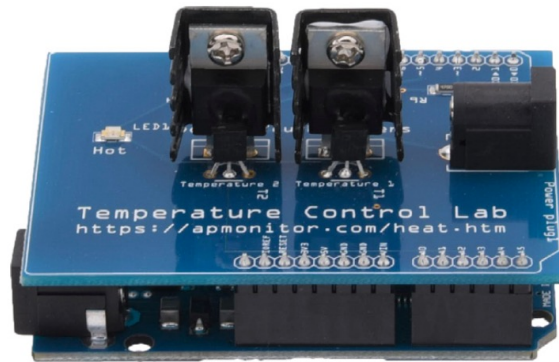
**Table 1**  
Normalized IAE and maximum integral values in the five examples.

	$IAE_{norm}$	$I_{max_{norm}}$
Example 1	0.63	0.31
Example 2	0.66	0.26
Example 3	0.68	0.62
Example 4	0.73	0.53
Example 5	0.26	0.53





# Examples



# 4 Conclusions

- The saturation problem on the feedforward control scheme was analyzed.
- The negative influence anti-windup functions on feedforward control actions was studied.
- A novel modification on the feedforward control scheme to deal with saturation problems was proposed.
- A general tuning rule was derived for the  $\alpha$  parameter.
- The new scheme was evaluated in simulation under different scenarios and experimentally on a temperature control problem.





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4th IFAC Conference on Advances in Proportional - Integral - Derivative Control (PID2014)  
Almería, June 12-14 2024

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**Important Dates:**

Oct 15, 2023	Submission Open
Dec 15, 2023	Submission Deadline
Mar 1, 2024	Notification of Acceptance
Mar 15, 2024	Early Registration Deadline
May 1, 2024	Late Registration Deadline

**Registration:**

Early full fee: 500 EUR
Early student fee: 250 EUR
Late full fee: 750 EUR
Late student fee: 500 EUR






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