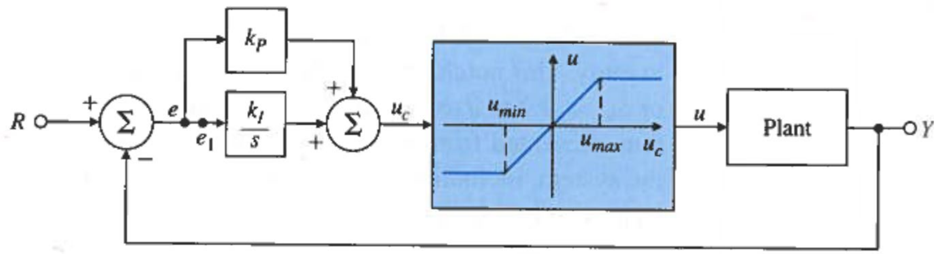
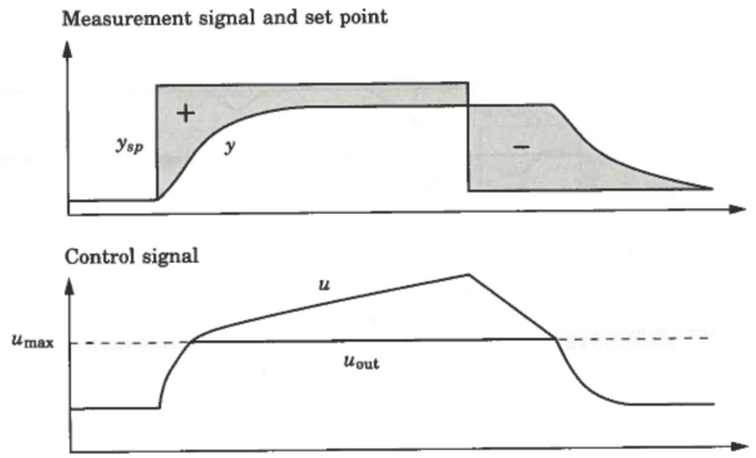
Integrator antiwindup

The actuator saturation problem

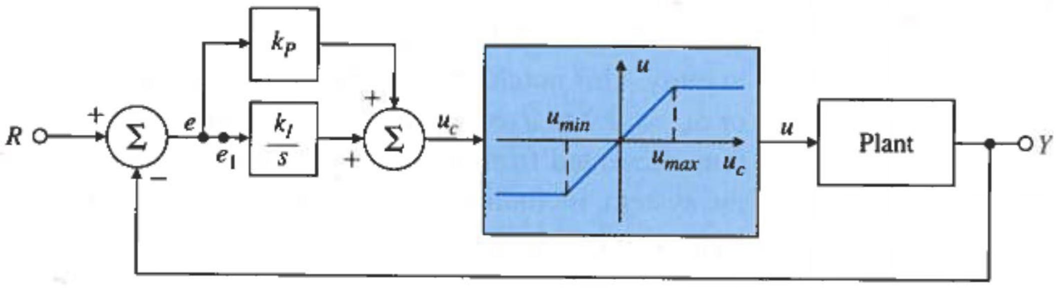
When the controller output saturates the control signal stops changing.
If the error signal continues to be applied to the integrator in a PI controller, the integrator output will grow until the sign of the error changes and the integration turn direction   (windup).

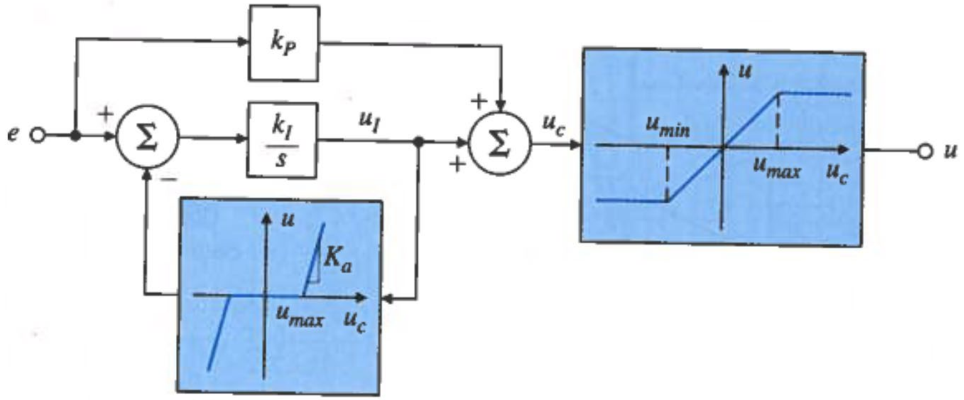
The result is a large overshoot and a poor transient response.





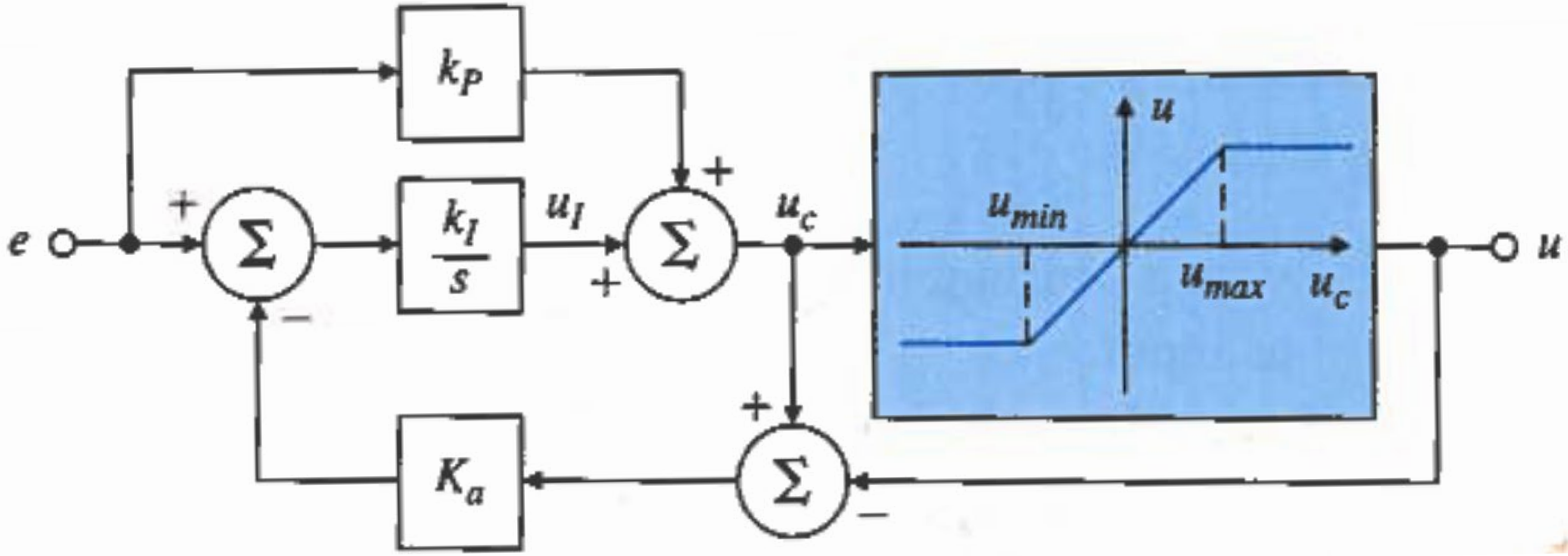
Integrator antiwindup



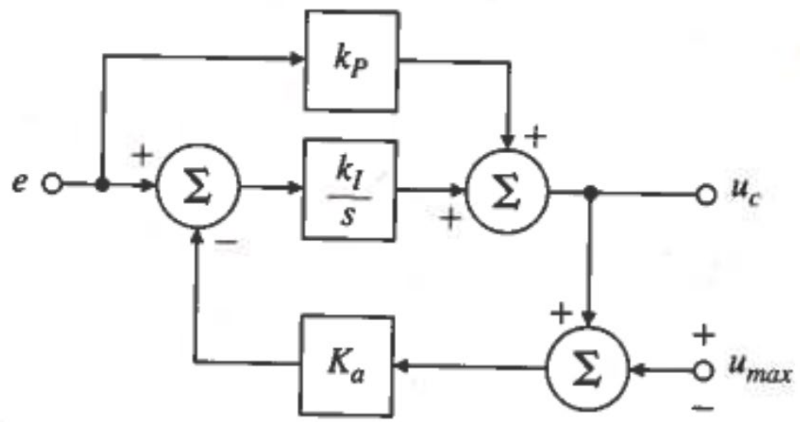


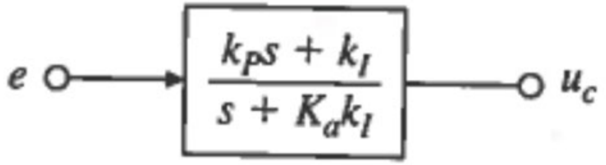
As soon as the actuator saturates the feed back loop around the integrator becomes active and keeps the input to the integrator small

Integrator antiwindup



Integrator anti windup





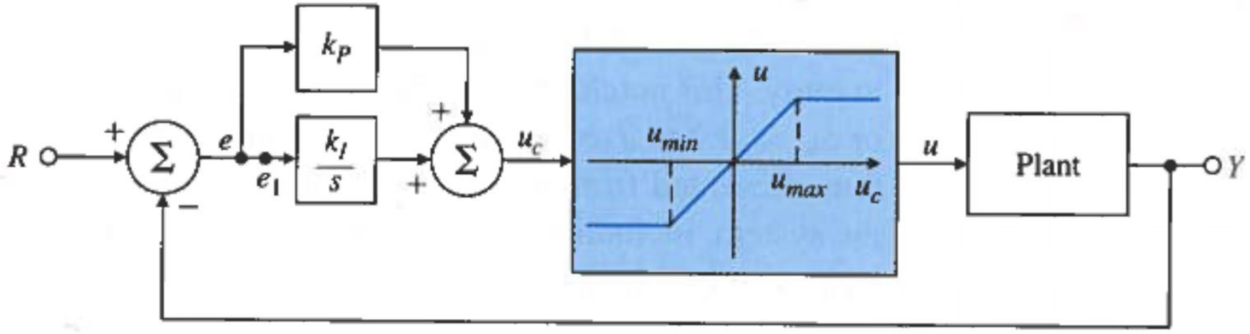
The structure corresponds to a lead controller

Integrator antiwindup

Digital implementation

If $|u_c| = u_{max}$ $then$
  $k_I = 0$

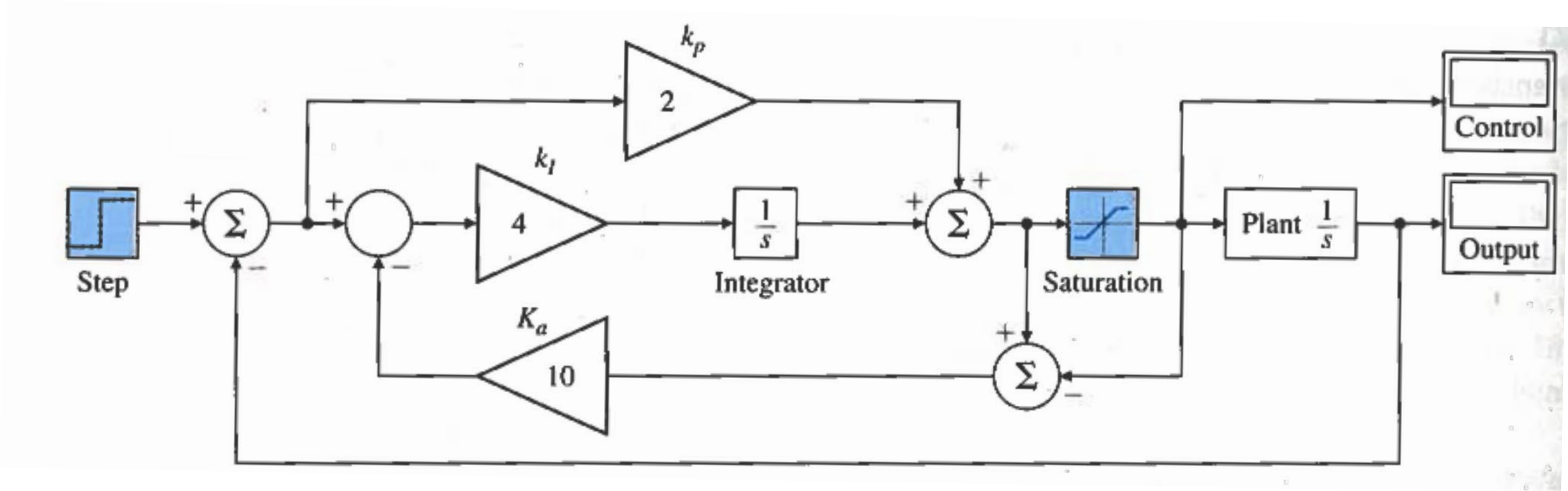
The integrator is reset when the control signal is saturated.



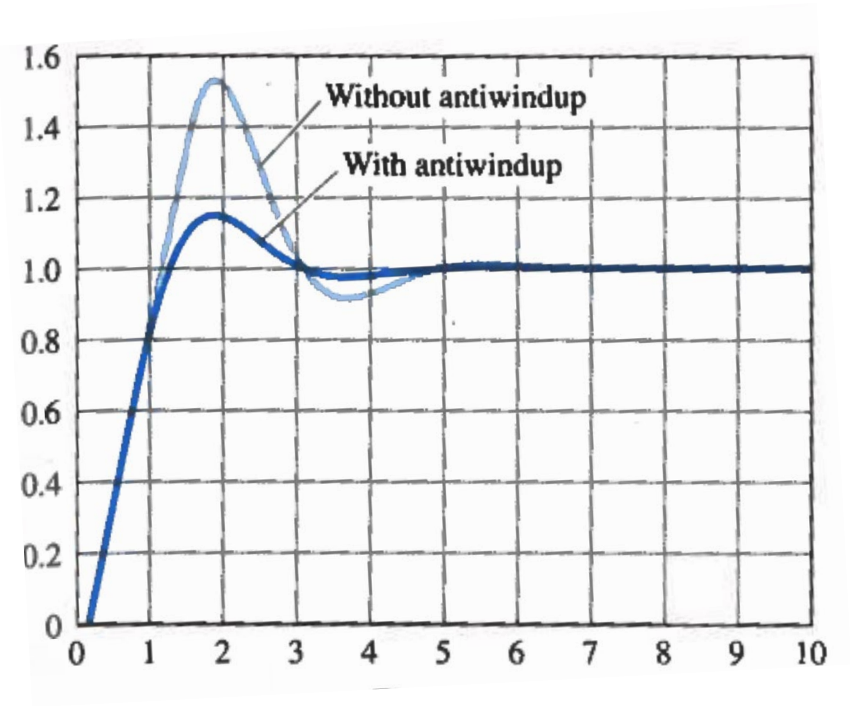
Example

$G(s) = \frac{1}{s}$ input to the plant is limited to ± 1.0

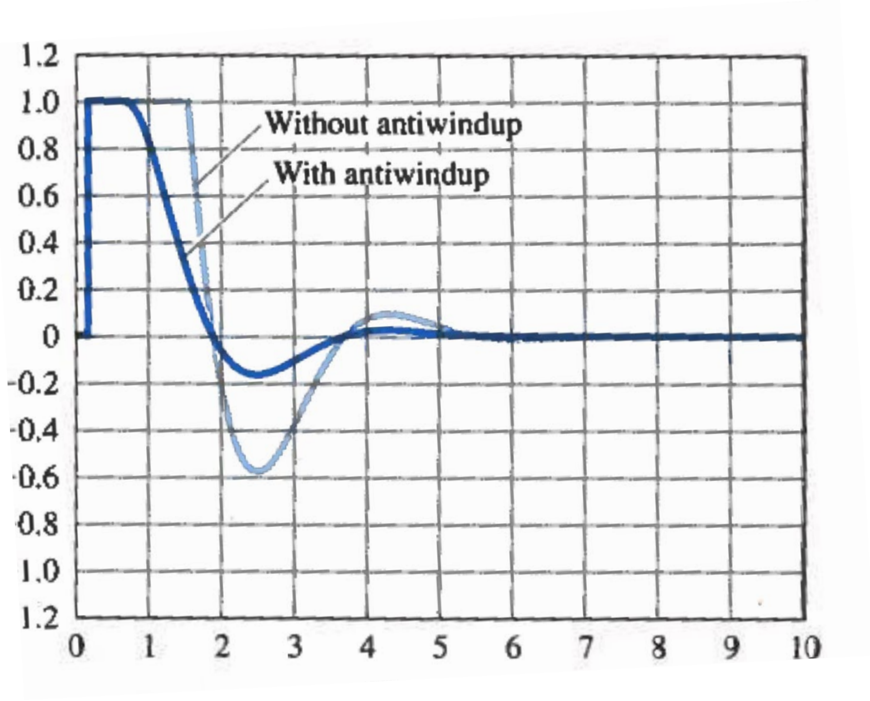
$D(s) = k_p + \frac{k_i}{s} = 2 + \frac{4}{s}$ $K_a = 10$



Simulation results



Stepresponse - output



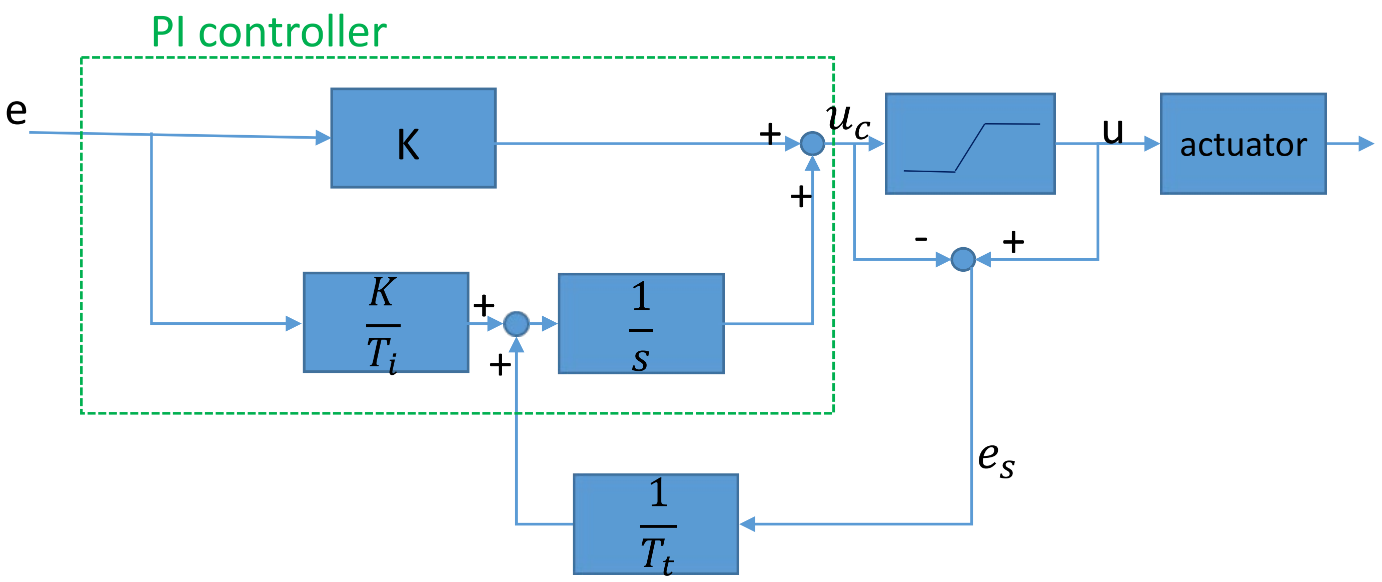
Stepresponse control effort

Back calculation and tracking

When the output saturates the integral term in the controller is re-calculated so that the new value gives an output at the saturation limit.

The integrator is not reset instantaneously but dynamically with a time constant T_t.

No saturation $u_c = u \Rightarrow e_s = 0$



Back calculation and tracking

The integrator input is

$$\frac{1}{T_t}e_s + \frac{K}{T_i}e \Rightarrow \; e_s = \frac{KT_t}{T_i}e$$

$$e_s = u_c - u_{max}$$

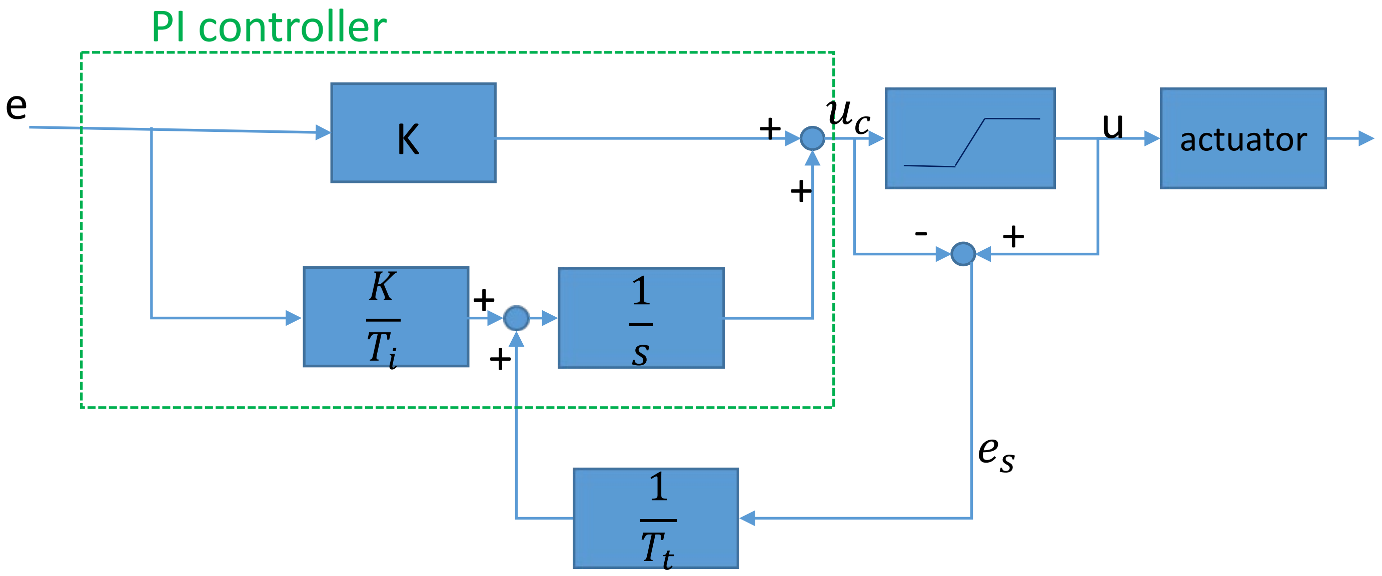
$$u_c = Ke + \frac{K}{T_i s}e + \frac{1}{T_t}\frac{1}{s}(-u_c + u_{max})$$

$$\frac{T_t s + 1}{T_t s}u_c = \frac{KT_i s + K}{T_i s}e + \frac{1}{T_t s}u_{max}$$

$$(T_t s + 1)u_c = \frac{(KT_i s + K)T_t}{T_i}e + u_{max}$$

In steady state ⇔ s=0

$$u_c = \frac{KT_t}{T_i}e + u_{max}$$



$u_c \geq u_{max}$.

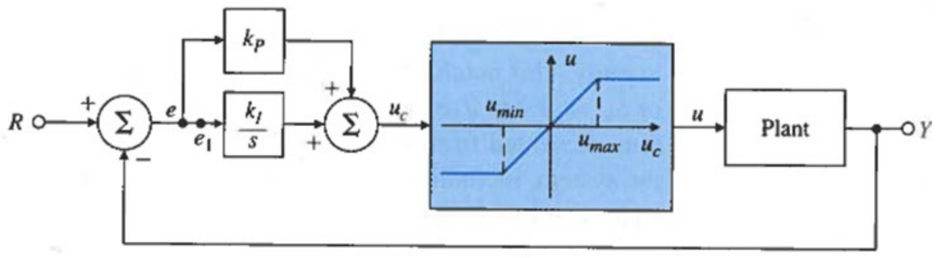
This prevent the integrator from winding up.

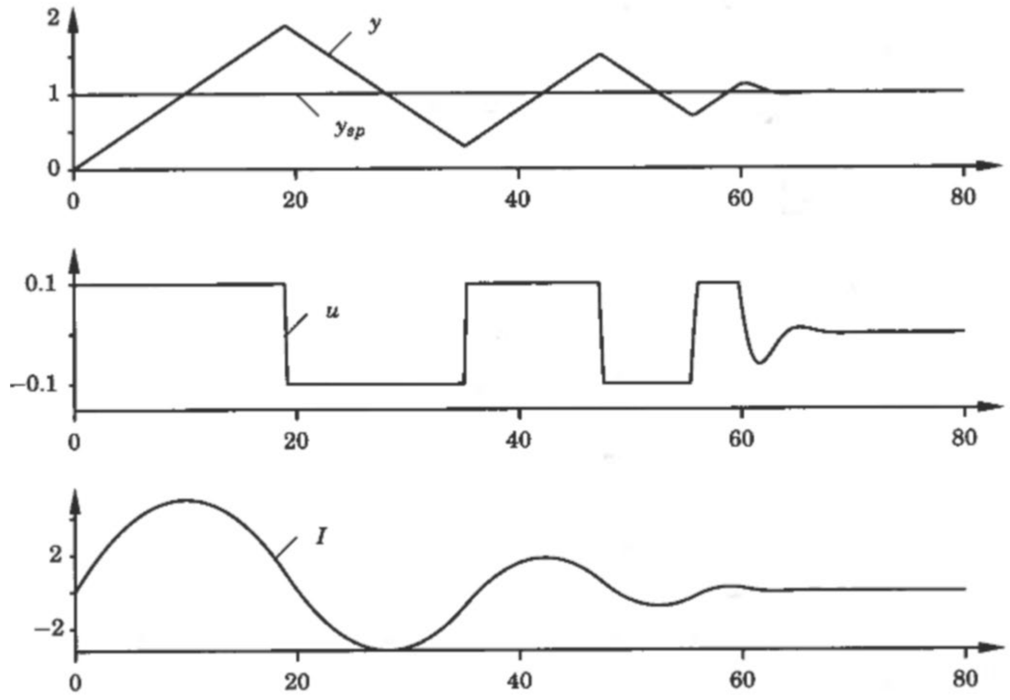
The rate at which the controller output is reset is governed by $\frac{1}{T_t}$,

T_t is a kind of time constant for how quick the integrator is reset.

T_t is also called the tracking time constant.

Back calculation and tracking

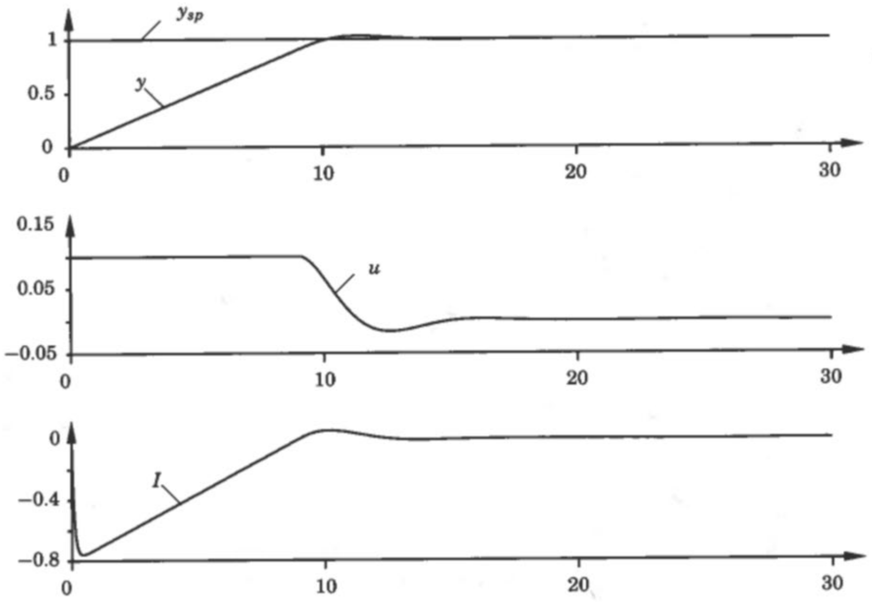


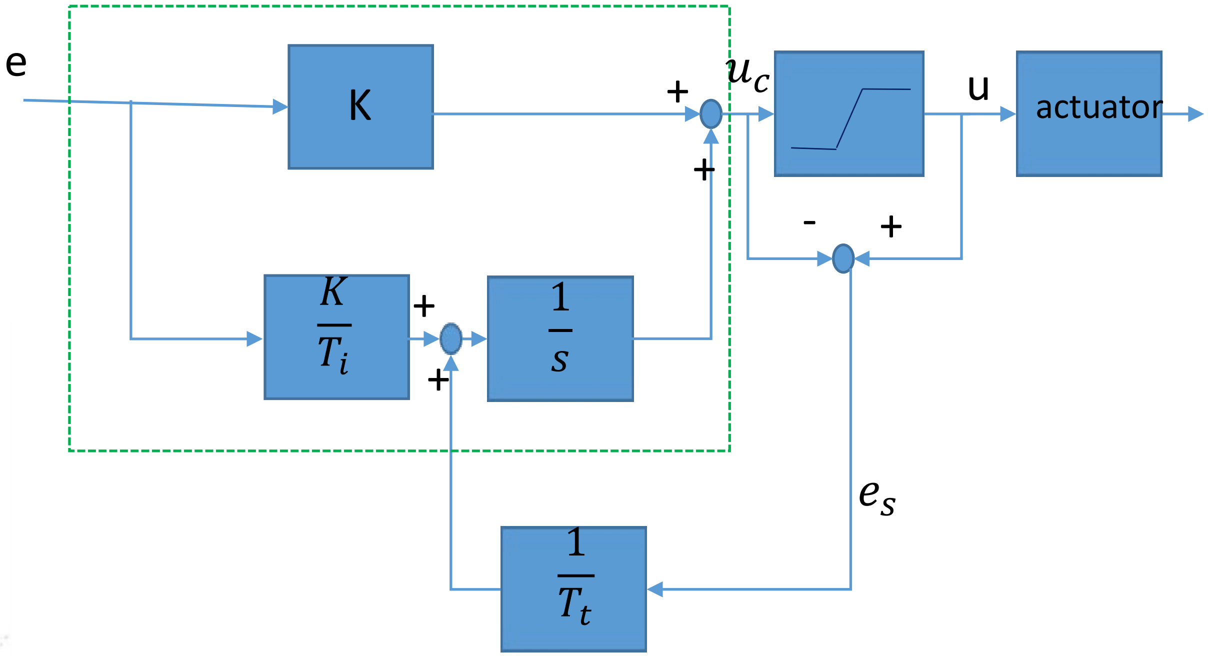


In the figure is the
output y,
setpoint y_{sp},
controlleroutput u
integration I

Back calculation and tracking

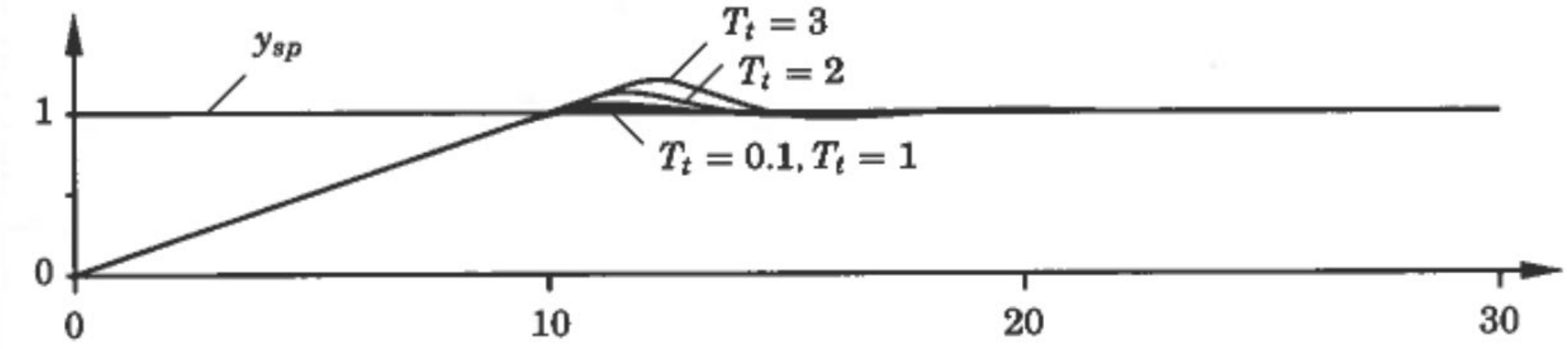
System including back calculation





Response for different tracking time T_t

Output y and setpoint y_{sp}



The control signal u