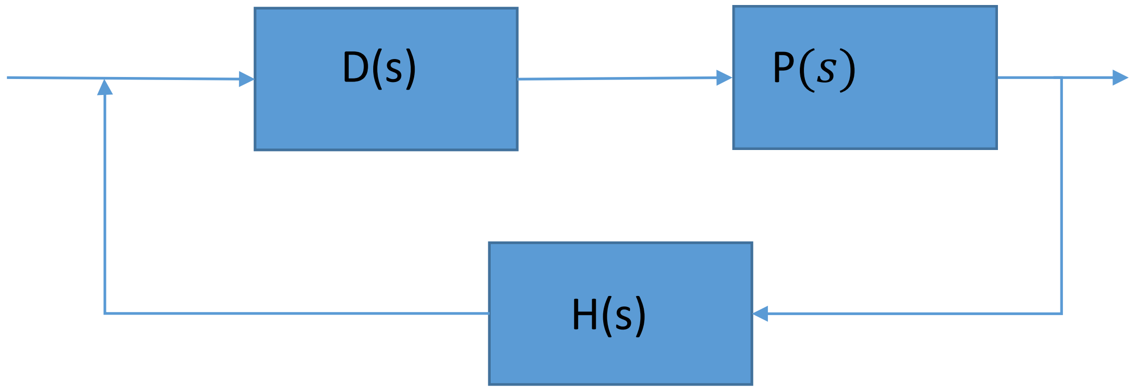
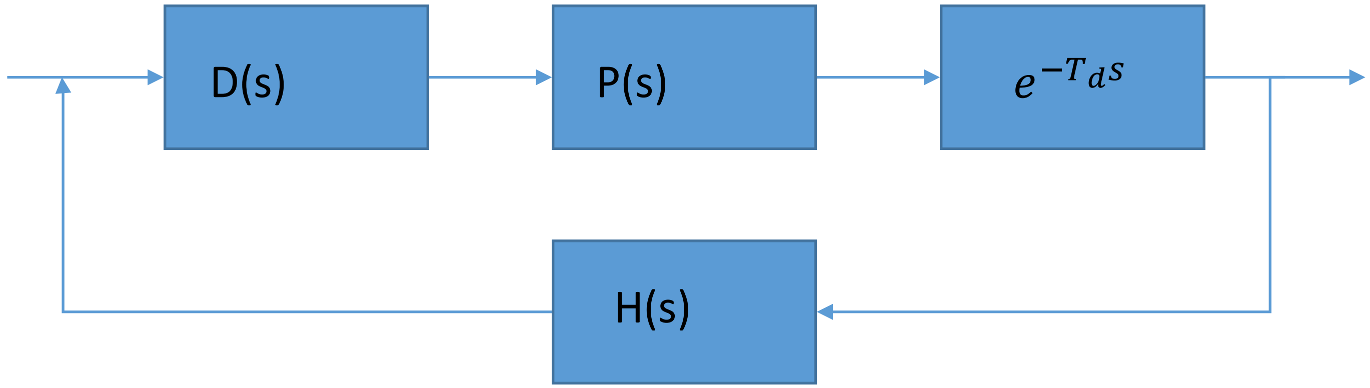
# Control of systems with delay
# The Smith predictor

# Systems with delays




Given a system with the transfer function $G(s) = \frac{1}{2s+1}$ and a large delay e.g. a transport delay $T_d = 20\ sec$

G



# Delays in control loops

*Example*

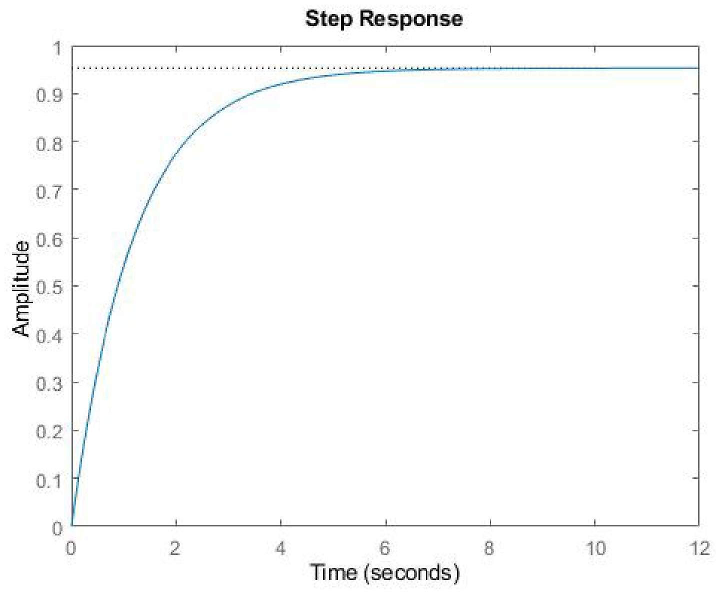
$$P(s) = \frac{2}{25s + 1}$$

$$P_d(s) = e^{-10s}$$

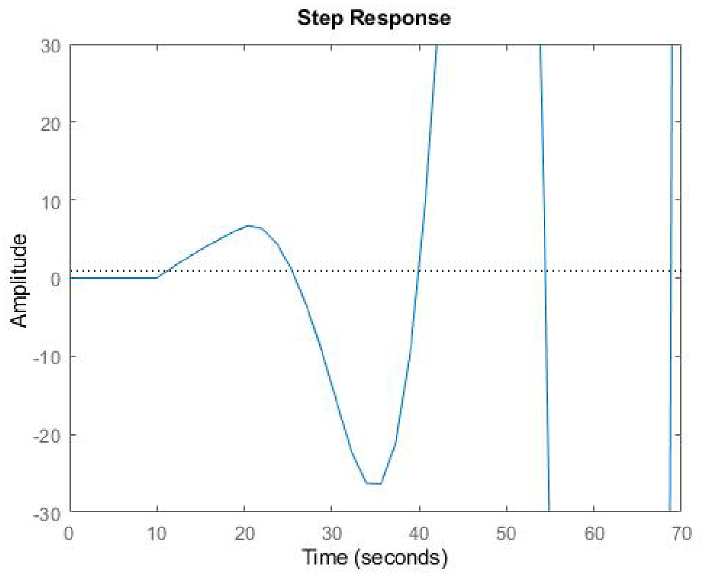
$$D(s) = 10$$

The delay causes instablity

Without delay




With delay



# Bodeplot of a delay

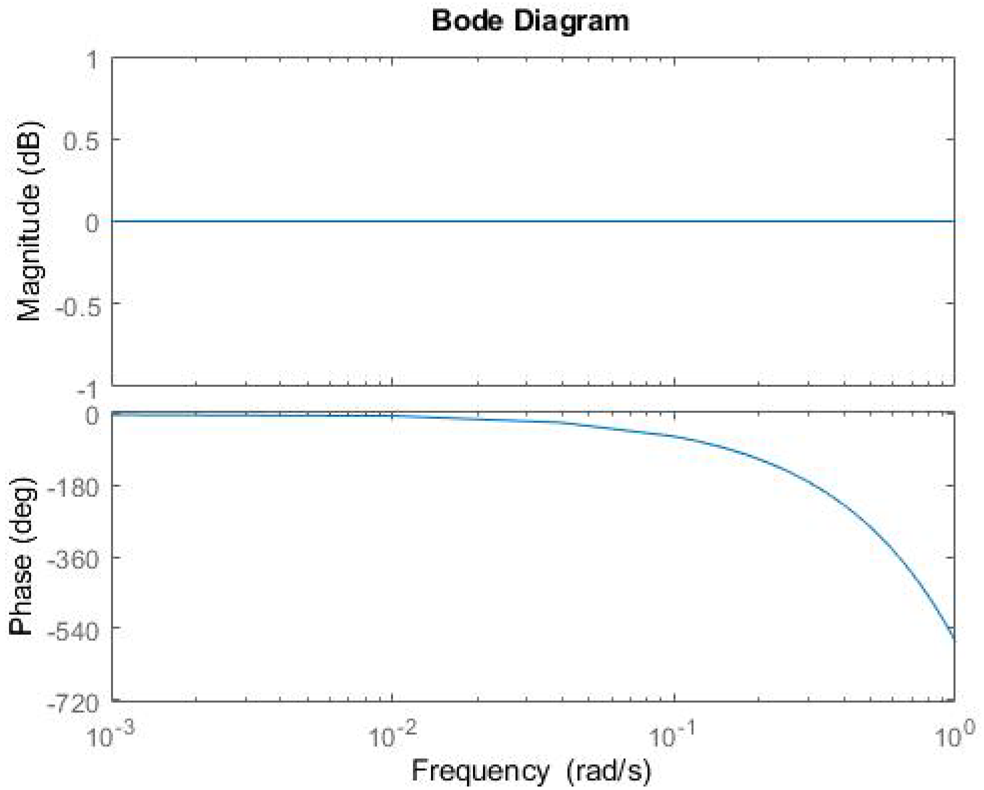
The time delay is $T_d = 10$

The La place transformed time delay is $e^{-T_d s}$

The Bodeplot for $T_d = 10$

You get a growing negative phaseshift

If you want a stable system you will need a low crossover frequency = a slow system



# Delays in control loops

*Example*

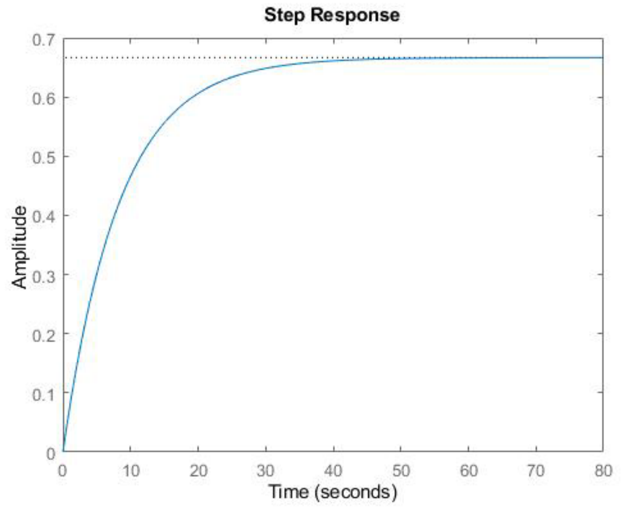
$$P(s) = \frac{2}{25s + 1}$$

$$P_d(s) = e^{-10s}$$

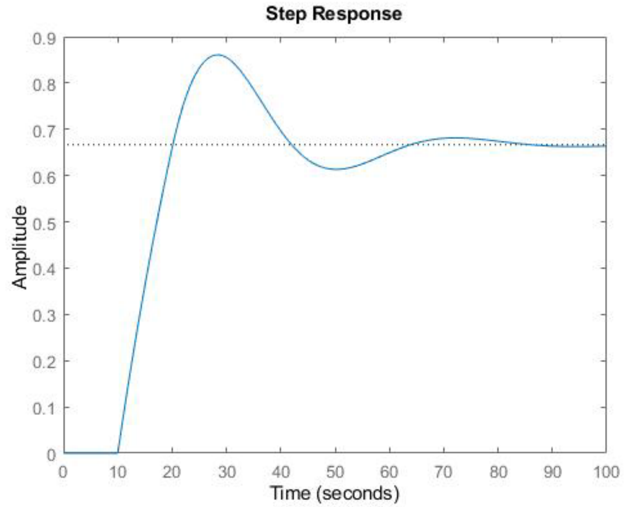
$$D(s) = 1$$

The time constant is larger than the delay
The system is stable, but the is a large stationary error

Without delay




With delay

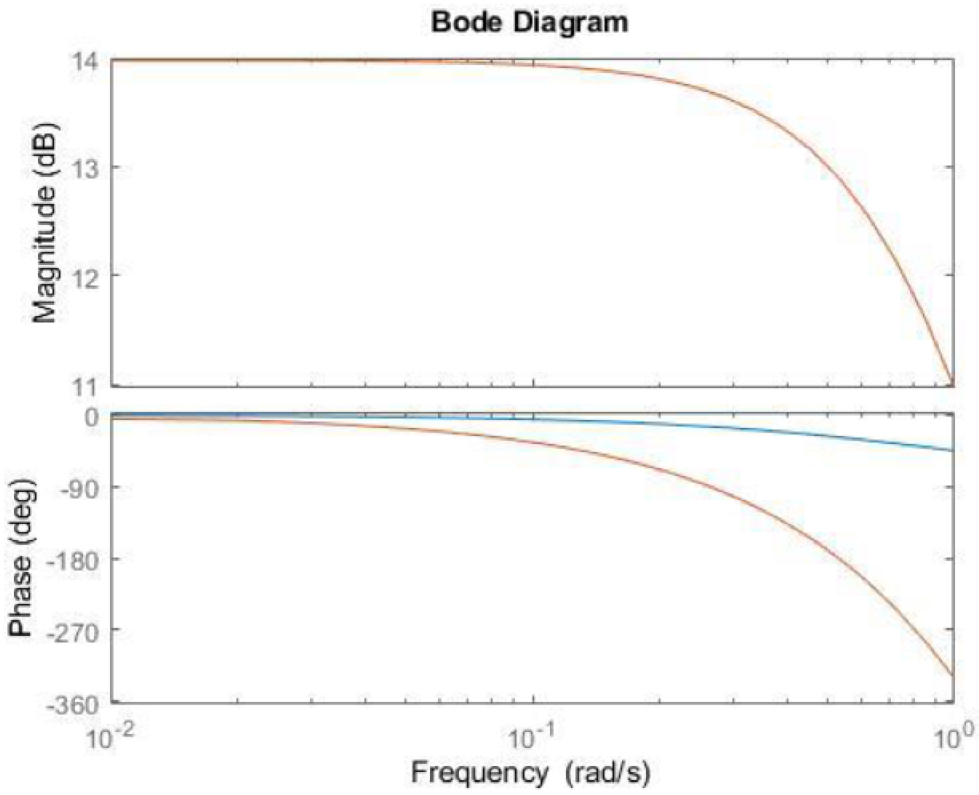


# Control of systems with delays

Timedelays causes bad stability

$$G(s) = \frac{5}{(s+1)}\, e^{-5s}$$

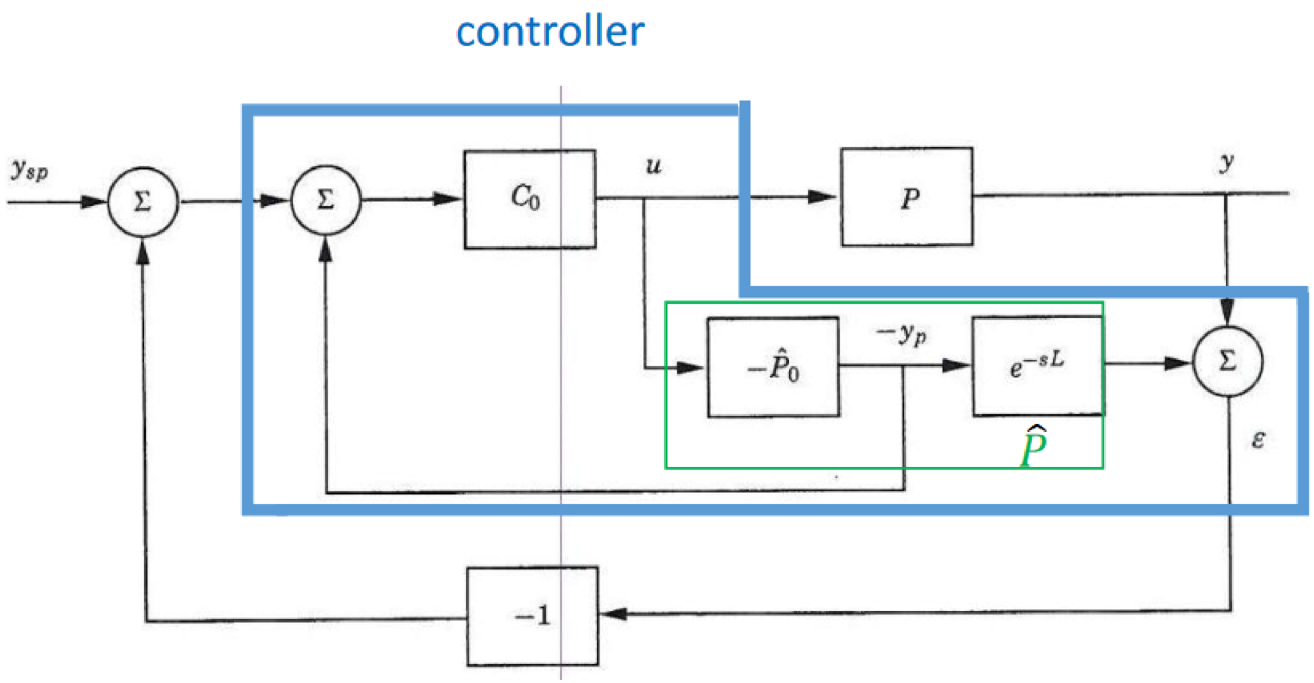
Is it possible to compensate for the delay in the control structure




Phase !!!!!!!

Bode plot with and without delay

# The Smith predictor




Given a system P(s) with a delay L

$$P(s) = P_0(s)e^{-sL}$$

The controller is

$C_0$ an ordinary PI/PID controller

$\hat{P}$ a model of the process

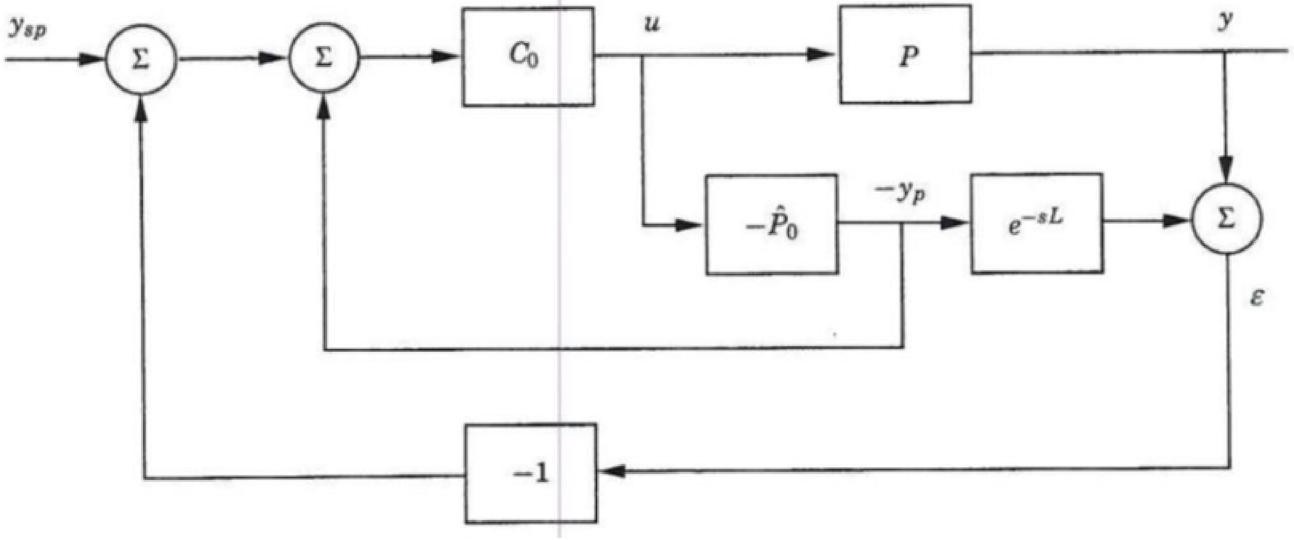
$\widehat{P_0}$ is the model with out time delay

$y_p$ is a prediction of the output without delay

$e^{-sL}$ is the timedelay

The output $y_p$ from $\widehat{P_0}$ represents the output without deay. It is used as feedback to the controller. An outer feedback is added to compensate for disturbances and differences between the system output and the timedelayed model output $\epsilon$.

# The Smith predictor



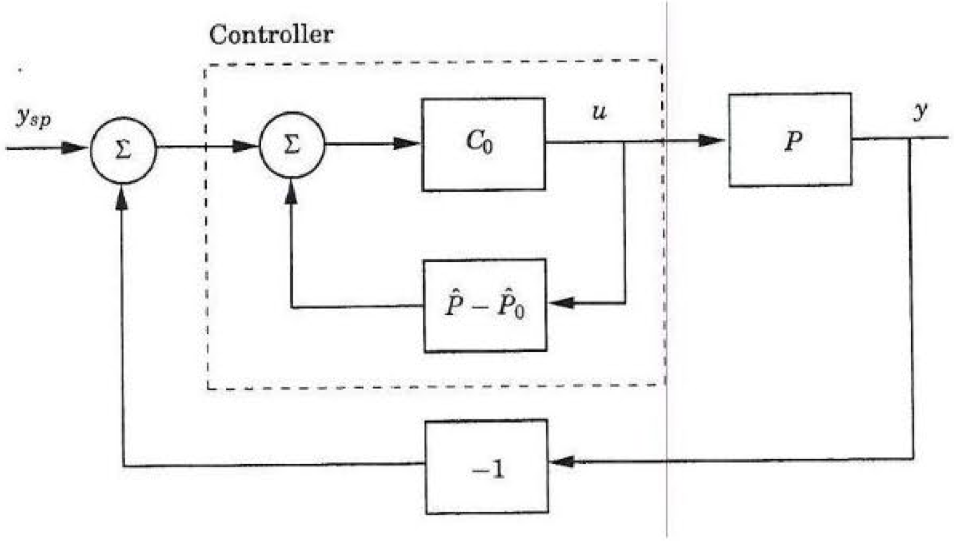

If $\varepsilon = 0$ the outer feedback loop gives no contribution.
The input output relation of the system is given as

$$G_{yy_{sp}} = \frac{PC_0}{1+P_0C_0} = \frac{P_0C_0}{1+P_0C_0}e^{-sL}$$

The controller $C_0$ can be designed as if there is no time delay and the response of the closed loop will have an additional time delay.

Very sensitive to model uncertainties

# Smith predictor - alternative representation




$$C = \frac{C_0}{1 + C_0(\hat{P}_0 - \hat{P})} = \frac{C_0}{1 + C_0\hat{P}_0(1 - e^{-sL})}.$$