Modelling, Poles and Zero's, Stepresponses

Job van Amerongen

Control Laboratory, Department of Electrical Engineering
University of Twente, Netherlands

www.ce.utwente.nl/amn
J.vanAmerongen@utwente.nl

Contents

- Modelling
  - Physical modelling
  - Black box
  - Grey box
- Descriptions
  - IPM's
  - Bond graph
  - Block diagram
  - Frequency characteristic
  - State space
  - Time response

Contents (2)

- Relations poles and zero's and step responses.
    - first order systems
    - second order systems
    - influence of zero's
    - initial and final value theorems.
- Relation between (step) responses and poles and zero's (identification)

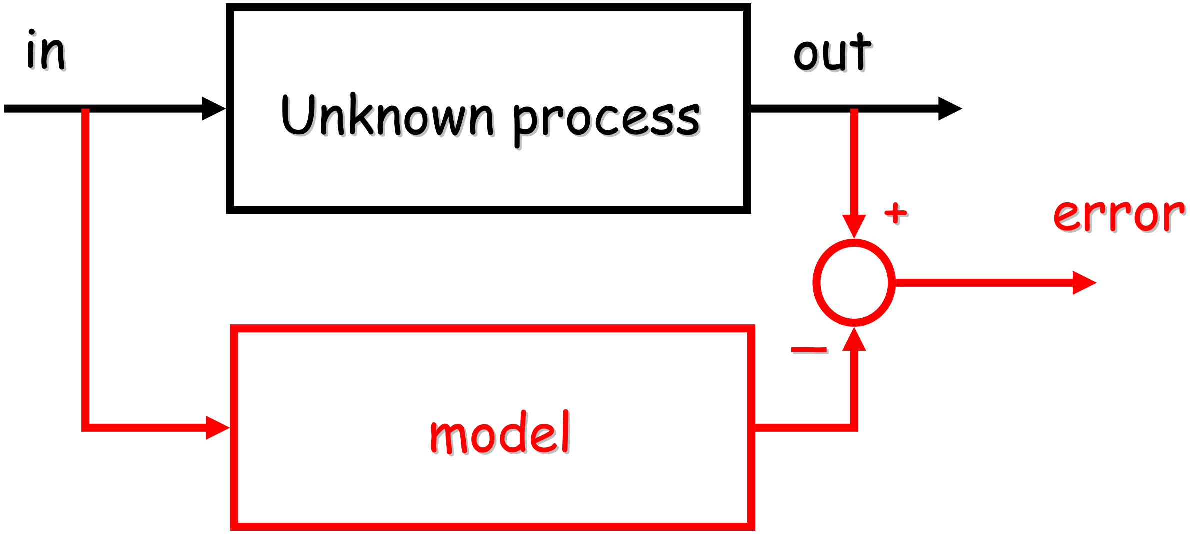
Physical modelling

- if a clear idea of the process and the various physical parts is available
- during the design of a (control) system

  - based on physical laws and geometrical properties (dynamische systemen)

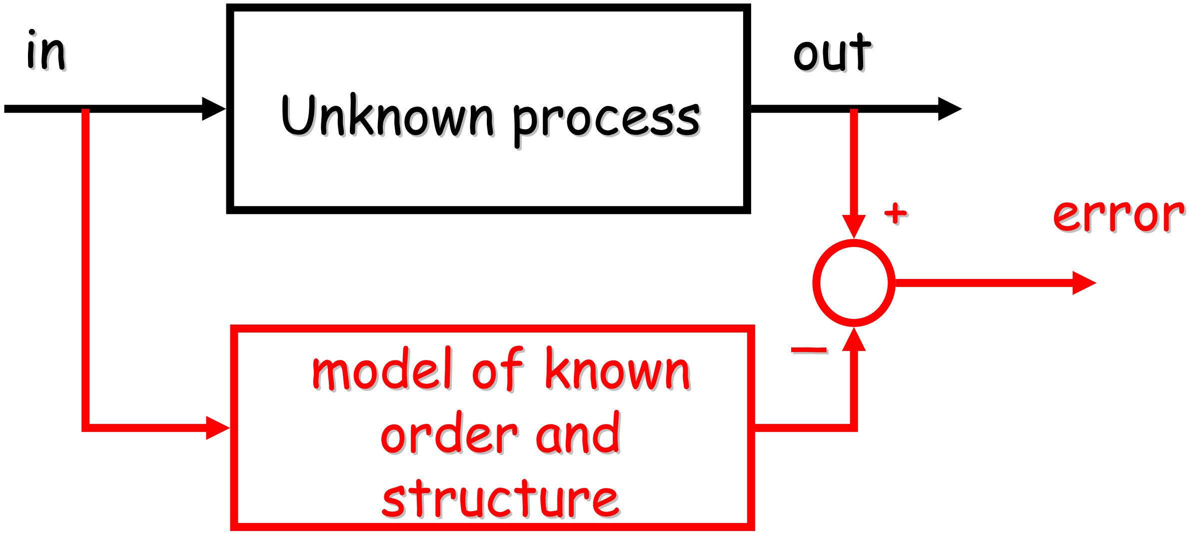
Black box modelling

- When only measurements are available



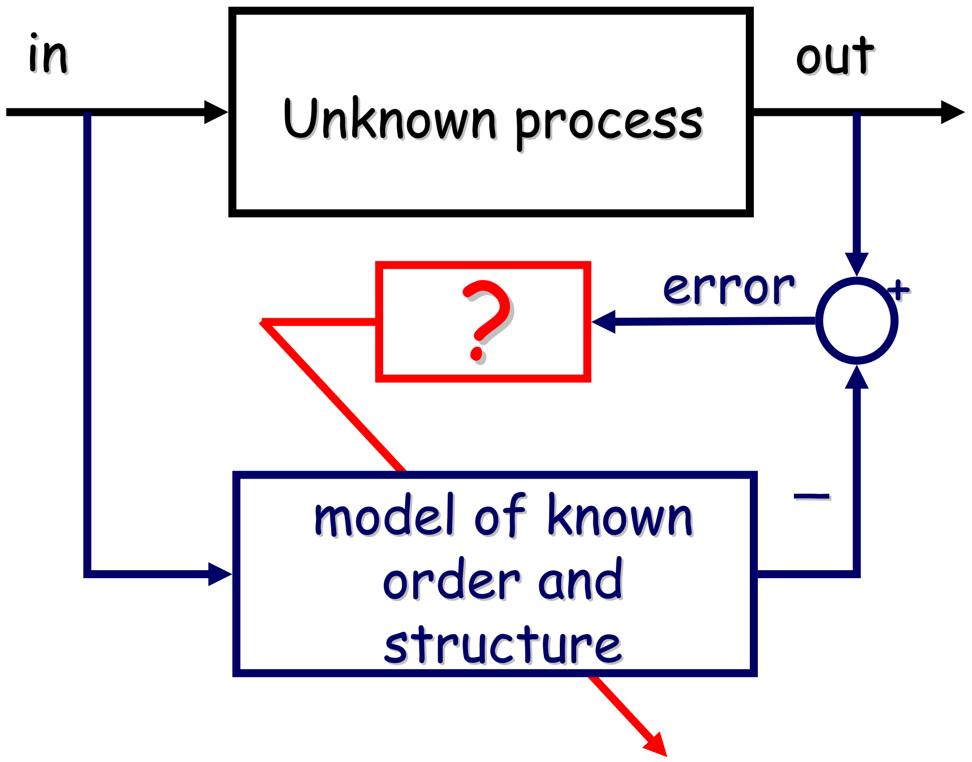
Grey box modelling

- Process structure and order is (assumed to be) known

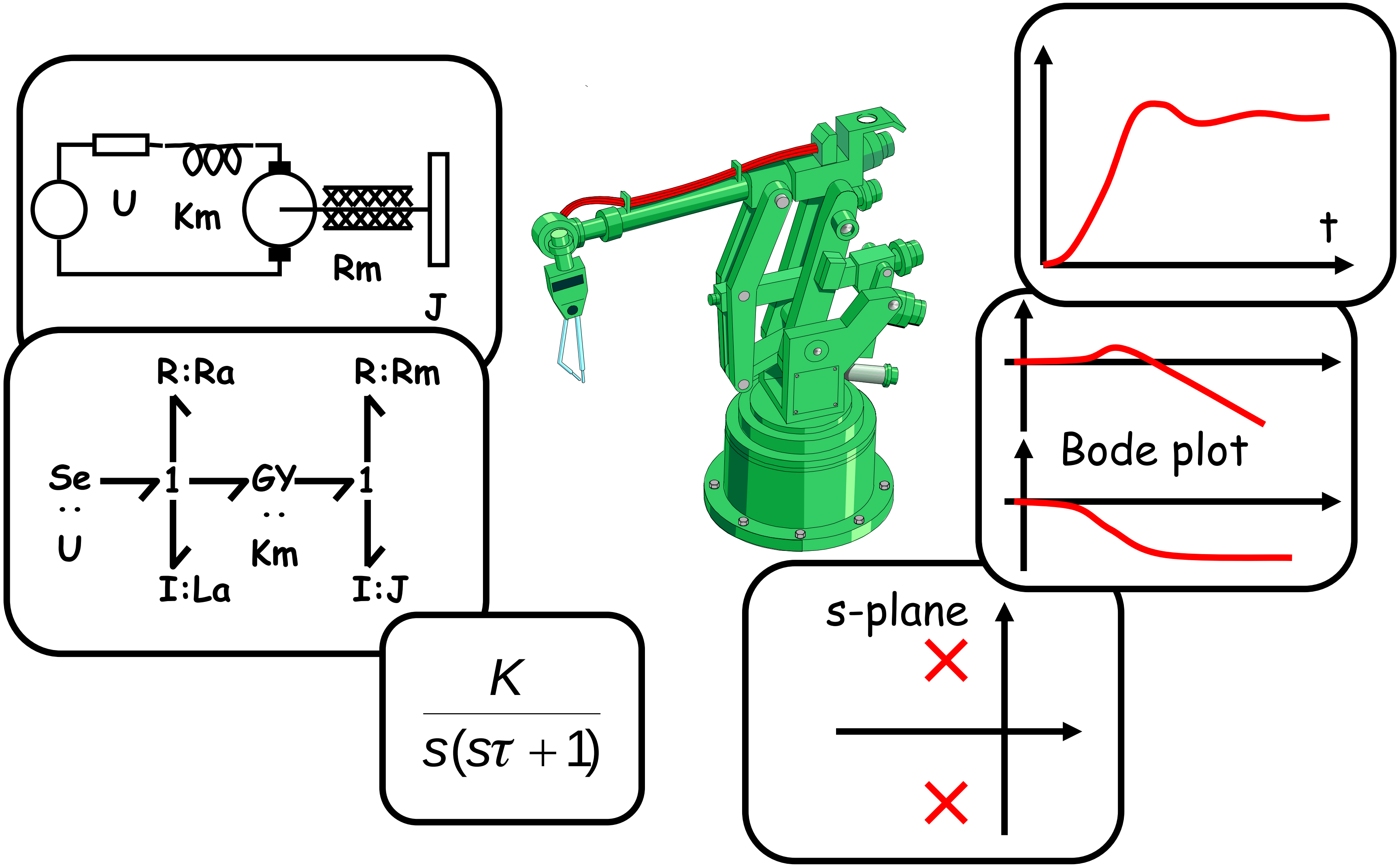


Grey box modelling

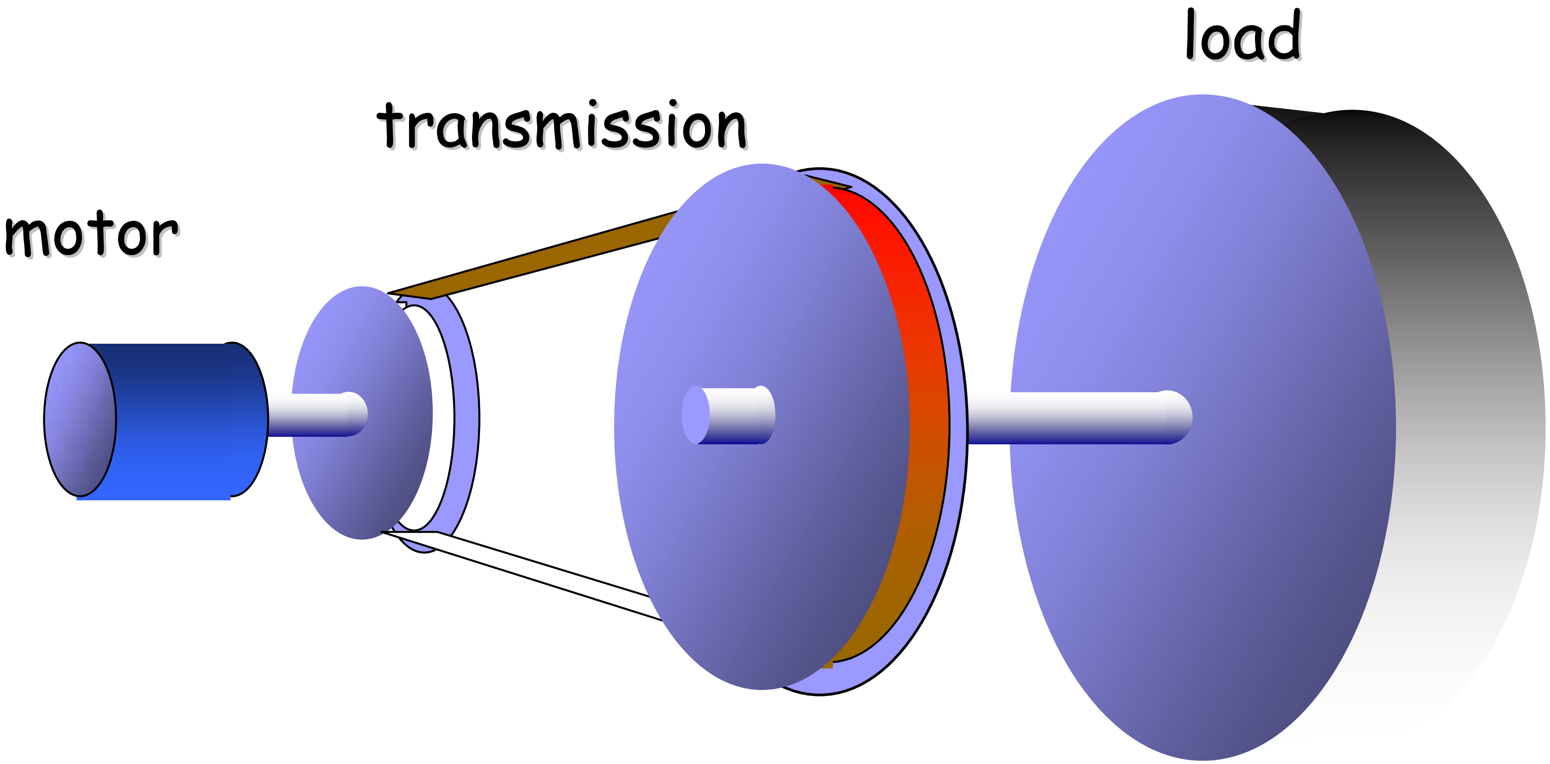
- Process structure and order is (assumed to be) known



Multiple views



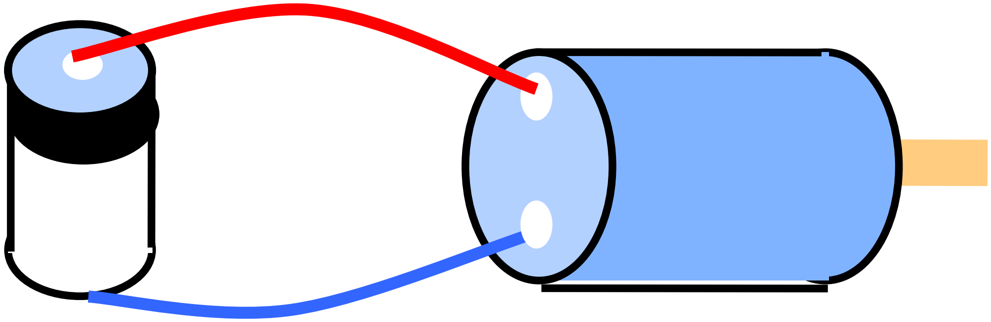
Process



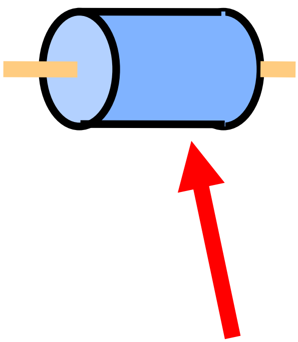
Physical modelling

- Starts with considering the components in the process
- Model the process with a suffiently level of detail
- i.e make a competent model

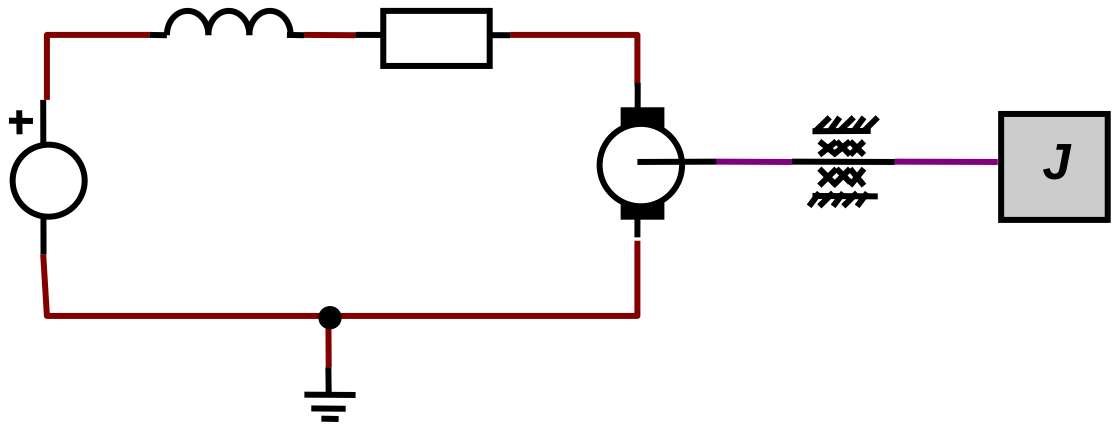
Simple DC-motor



Ideal Physical Model



component

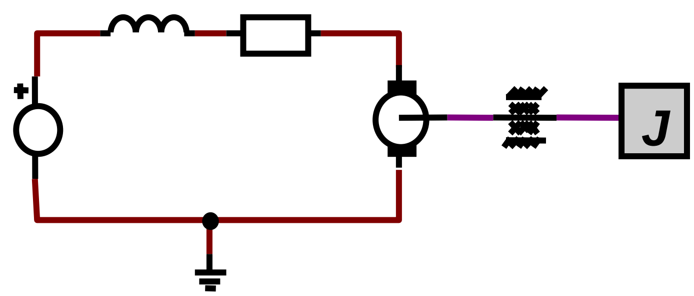


Ideal elements

IPM → equations

$$U - L_a \frac{di}{dt} - K_m \omega - R_a i_a = 0$$

$$K_m i - J \frac{d\omega}{dt} - R_m \omega = 0$$



$$L_a \frac{di}{dt} + R_a i_a = U - K_m \omega$$

$$J \frac{d\omega}{dt} + R_m \omega = K_m i$$

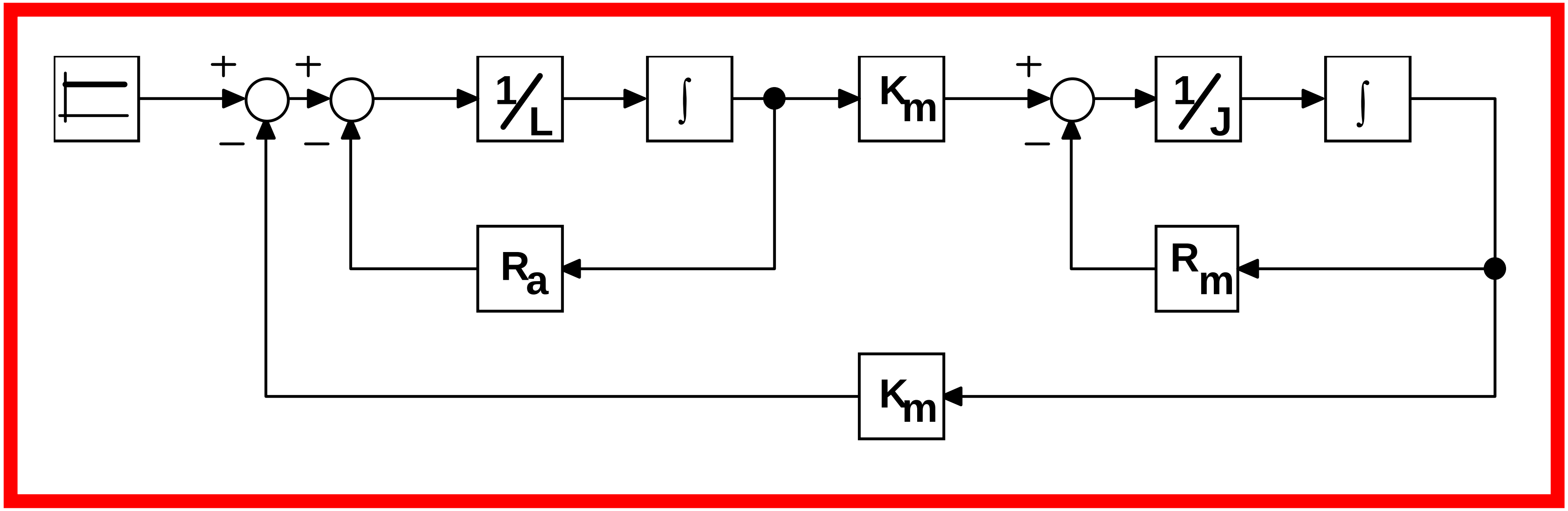
$$i_a = \frac{1}{L_a} \int \left(U - K_m \omega - R_a i_a \right) dt$$

$$\omega = \frac{1}{J} \int \left(K_m i - R_m \omega \right) dt$$

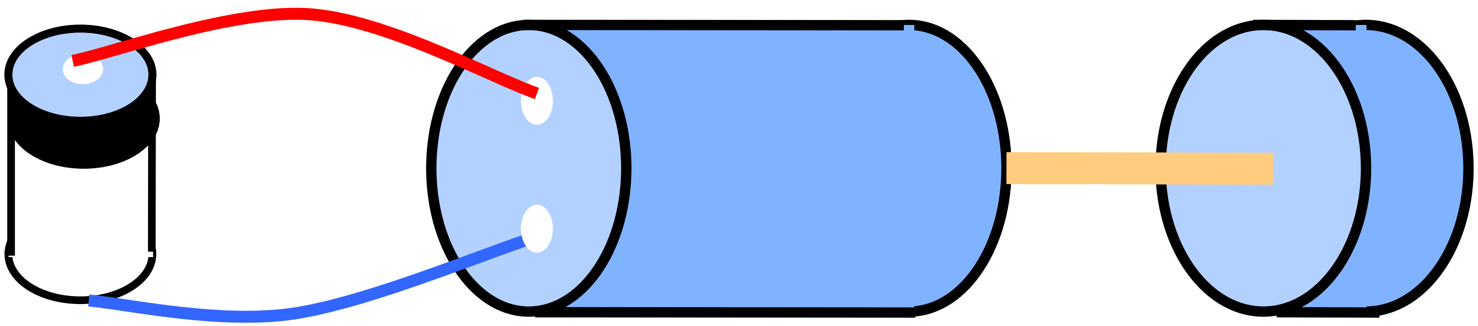
equations → block diagram

$$i_a = \frac{1}{L_a}\int\left(U - K_m\omega - R_a i_a\right)\mathrm{d}t$$

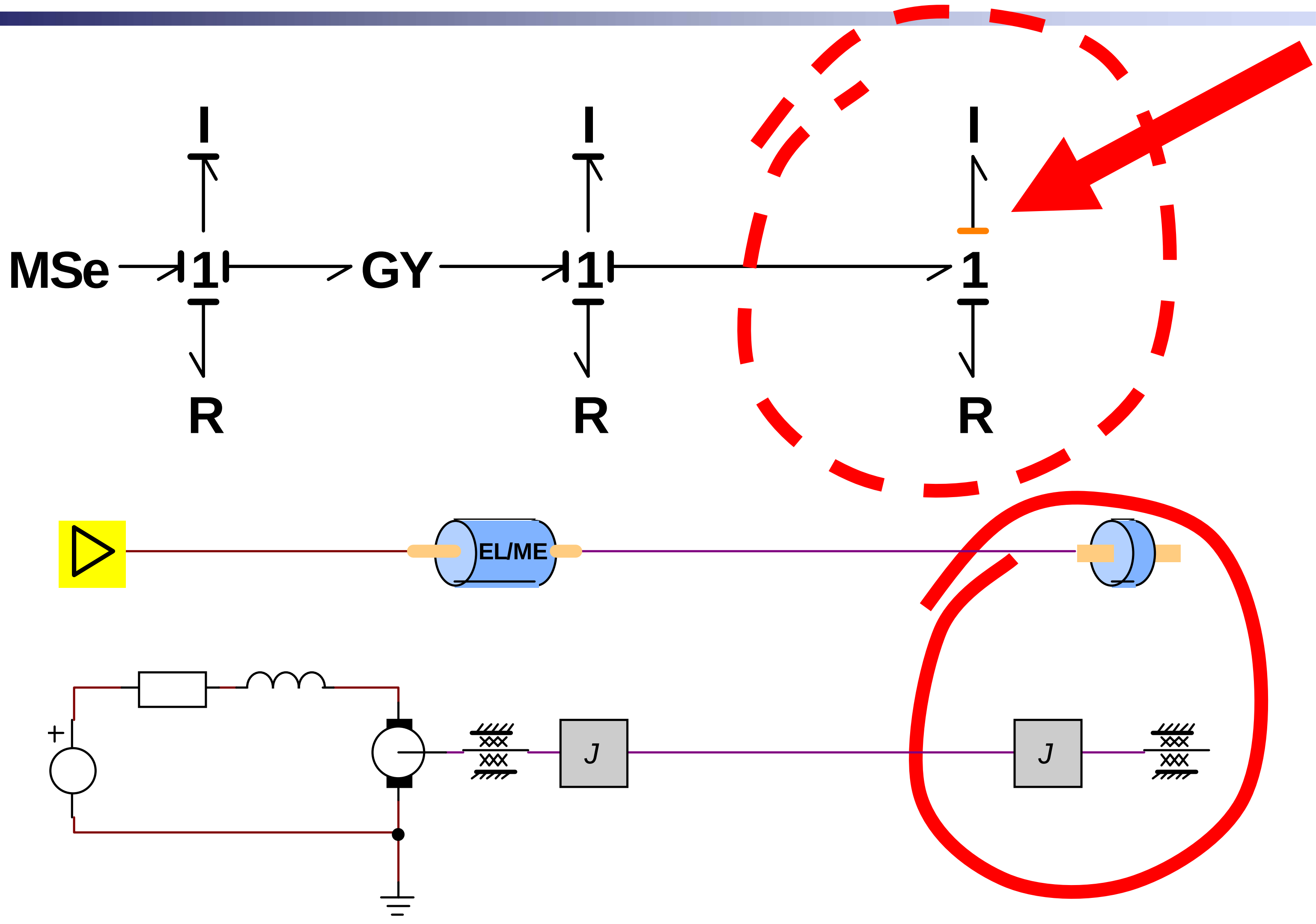
$$\omega = \frac{1}{J}\int\left(K_m i - R_m\omega\right)\mathrm{d}t$$



DC-motor + Load

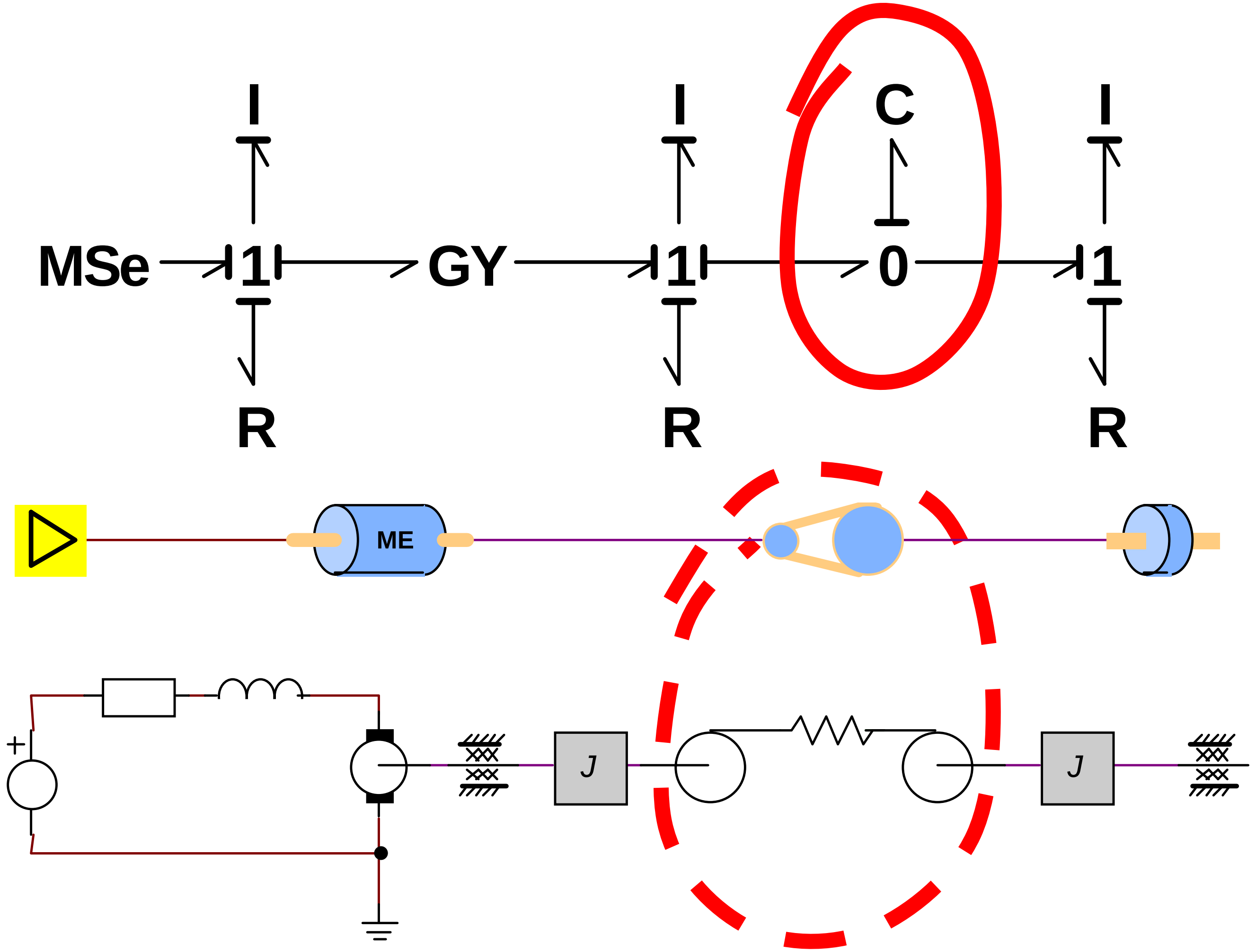


Add the load



Add flexible axis

Control Engineering
University of Twente



IPM → equations

$$U - L_a \frac{di}{dt} - K_m \omega_1 - R_a i_a = 0$$

$$K_m i_a - J_1 \frac{d\omega_1}{dt} - R_m \omega$$

$$\frac{1}{C}\left(\int \left(\omega_1 - \omega_1\right) dt\right) -$$

$$i_a = \frac{1}{L_a}\left(\int \left(U - K_m \omega_1 - R_a i_a\right) dt\right)$$

$$\omega_1 = \frac{1}{J_1}\left(\int \left(K_m i_a - R_m \omega_1 - T_{spring}\right) dt\right)$$

$$T_{spring} = \frac{1}{C}\left(\int \left(\omega_1 - \omega_2\right) dt\right)$$

$$\omega_2 = \frac{1}{J_2}\left(\int \left(T_{spring} - R_m \omega_2\right) dt\right)$$

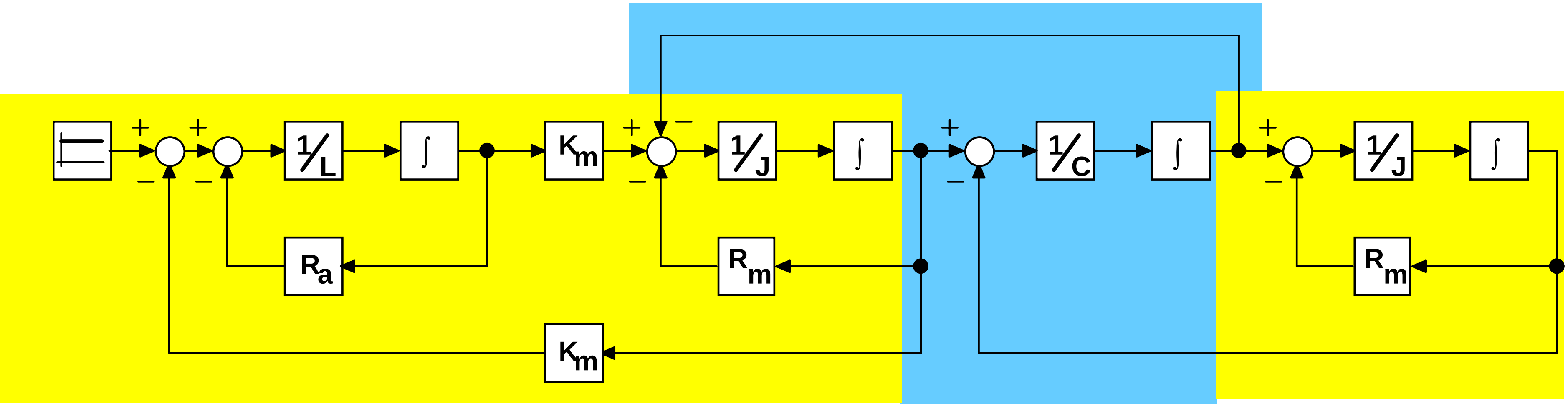
Block Diagram

$$i_a = \frac{1}{L_a}\left(\int\left(U - K_m\omega_1 - R_a i_a\right)\mathrm{d}t\right)$$

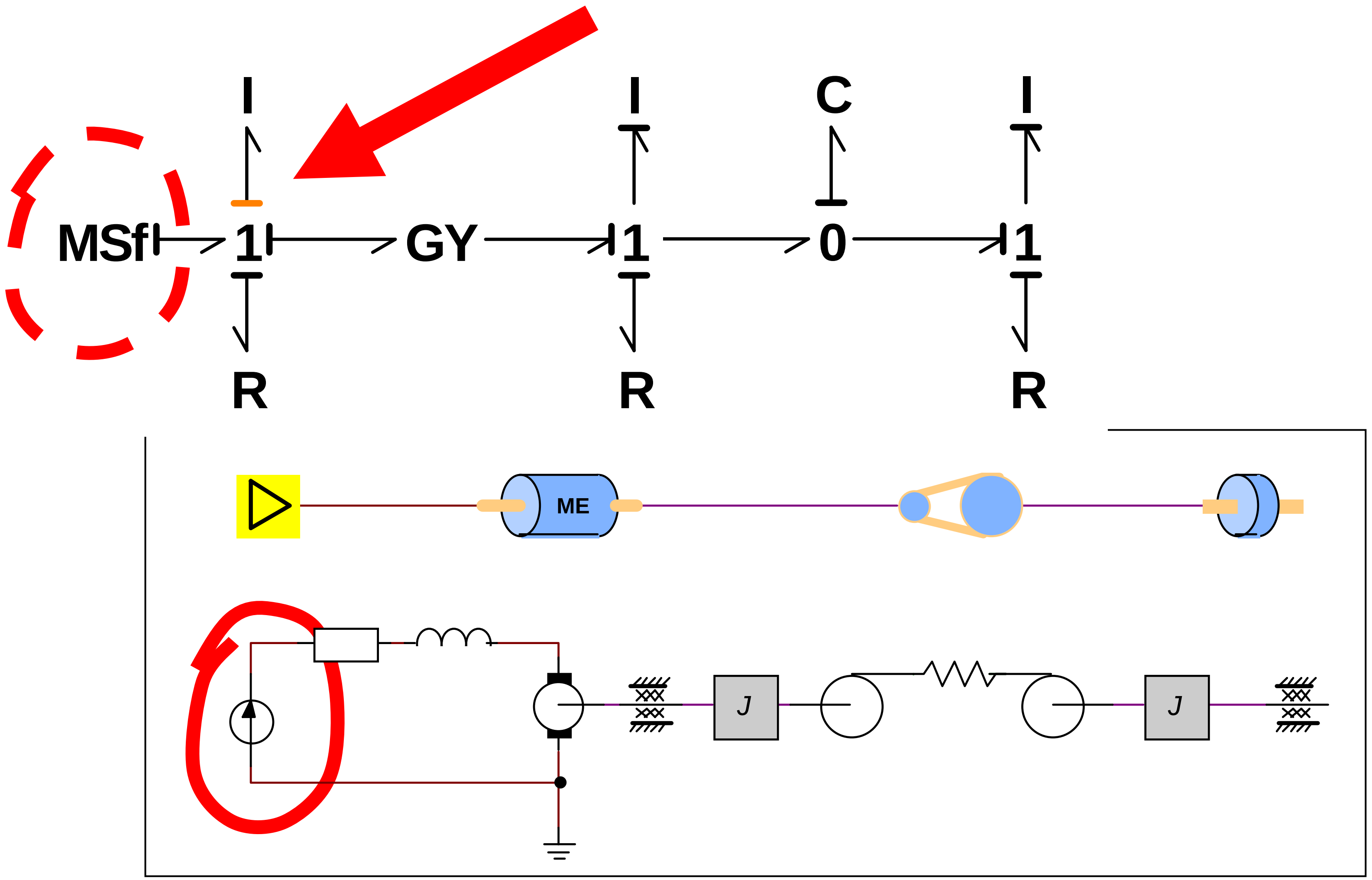
$$\omega_1 = \frac{1}{J_1}\left(\int\left(K_m i_a - R_m\omega_1 - T_{spring}\right)\mathrm{d}t\right)$$

$$T_{spring} = \frac{1}{C}\left(\int\left(\omega_1 - \omega_2\right)\mathrm{d}t\right)$$

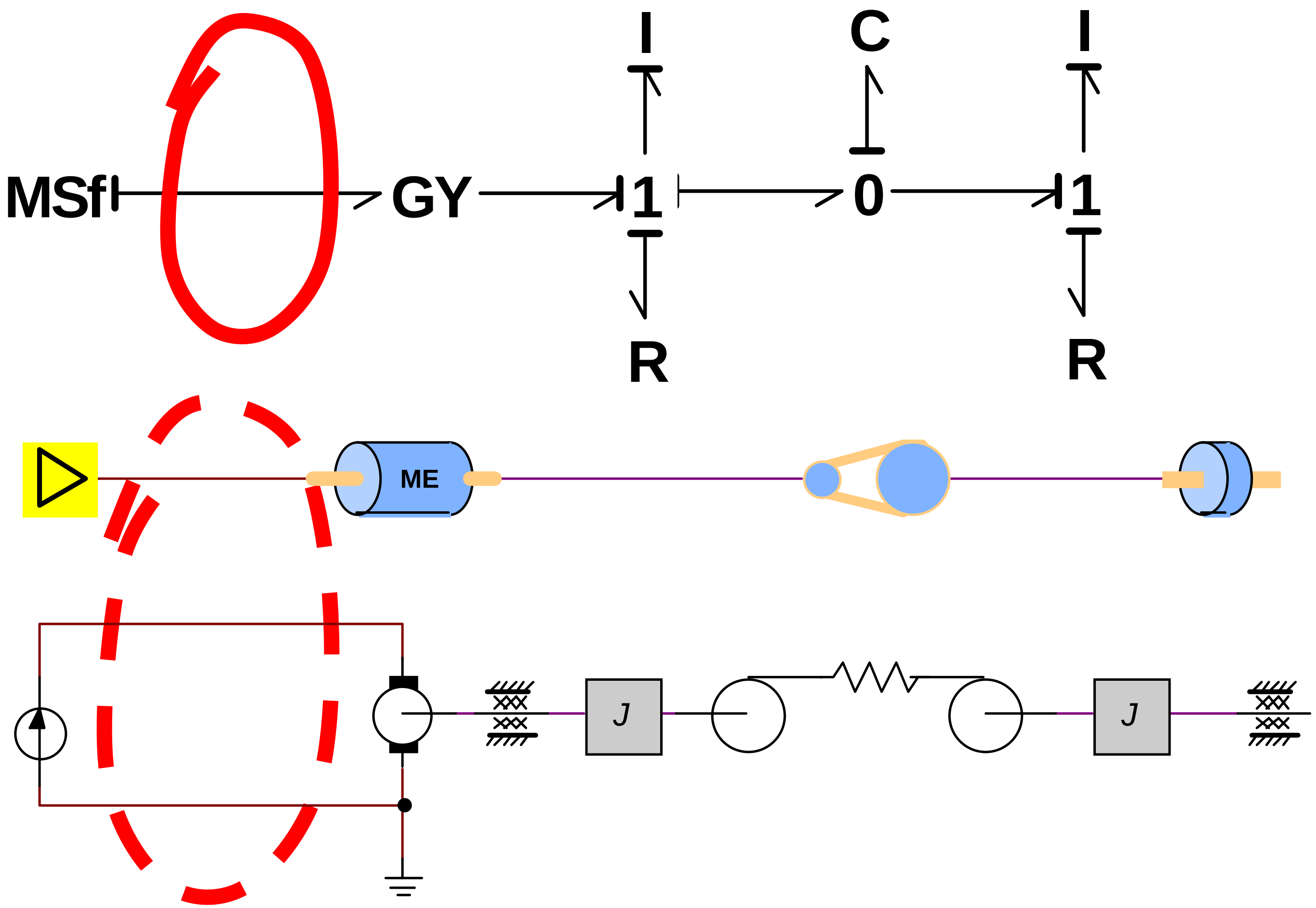
$$\omega_2 = \frac{1}{J_2}\left(\int\left(T_{spring} - R_m\omega_2\right)\mathrm{d}t\right)$$



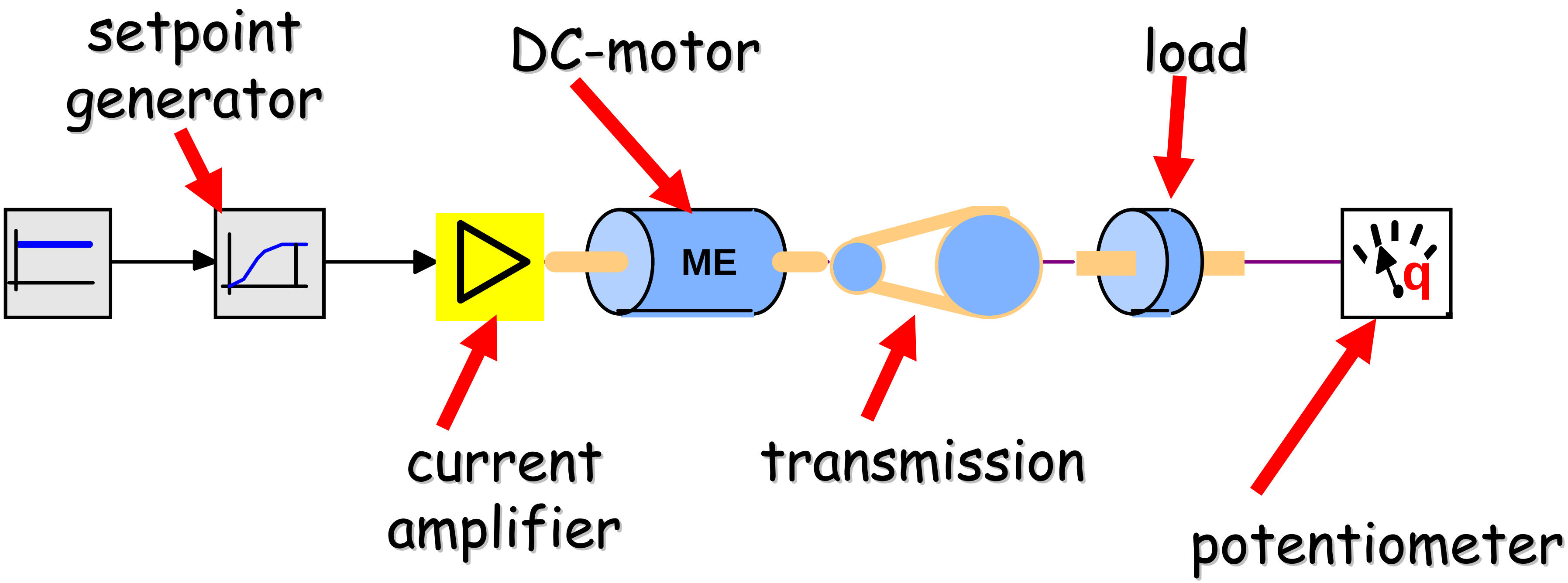
Use current amplifier



No electrical time constant

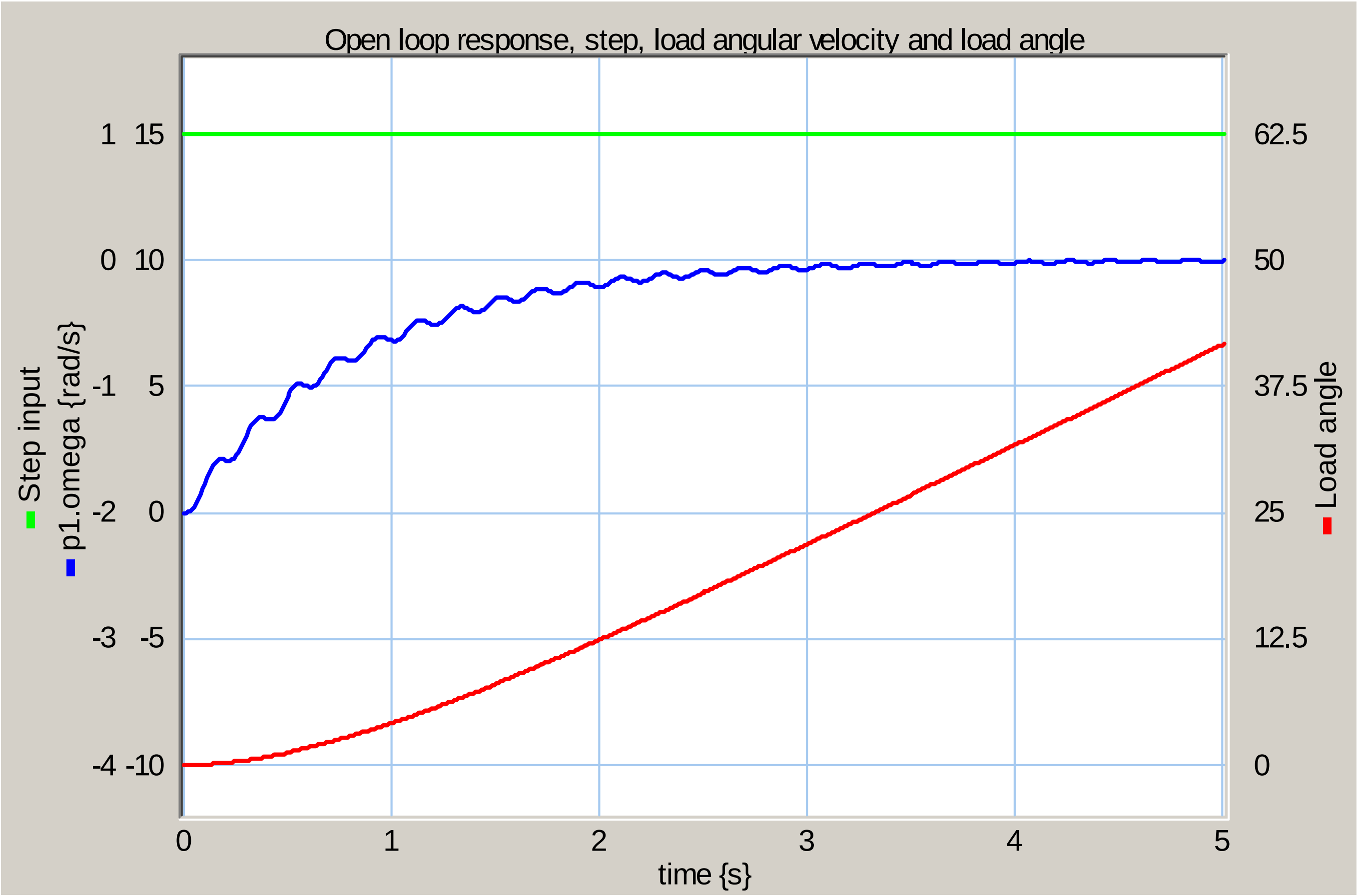


Demo process

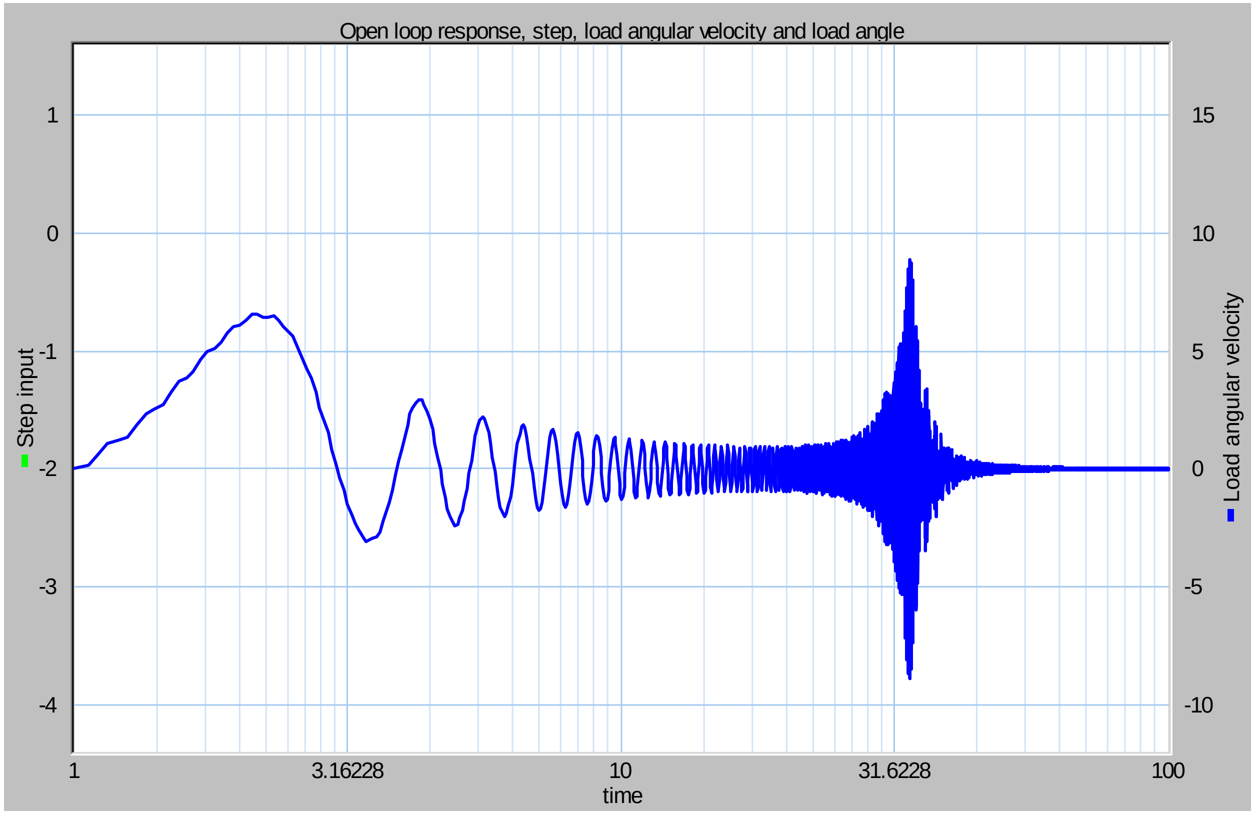


20-sim
demo

Step response

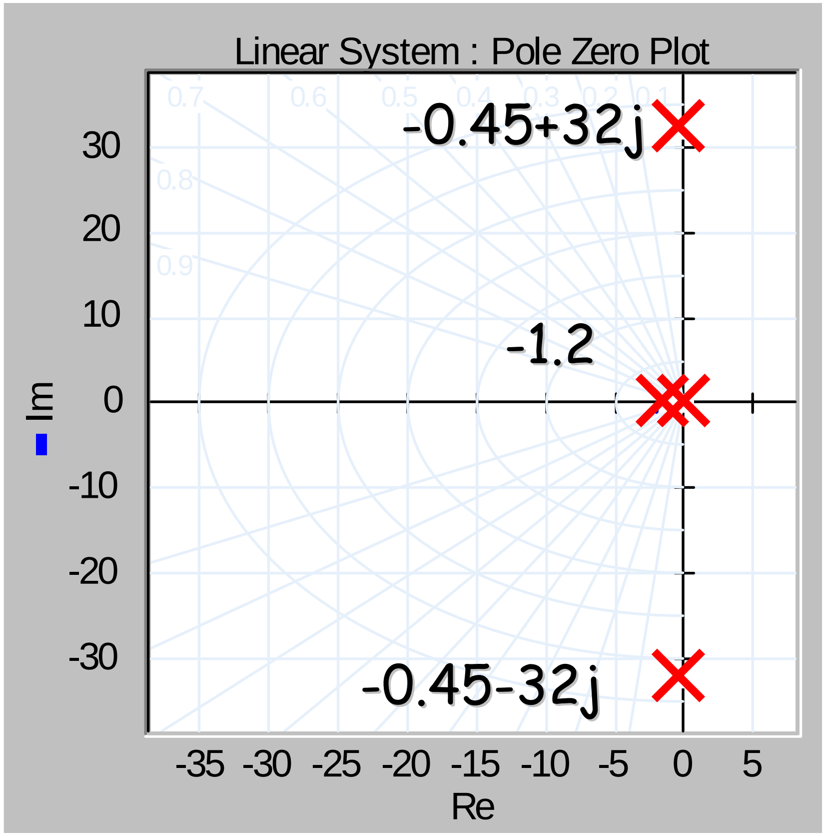


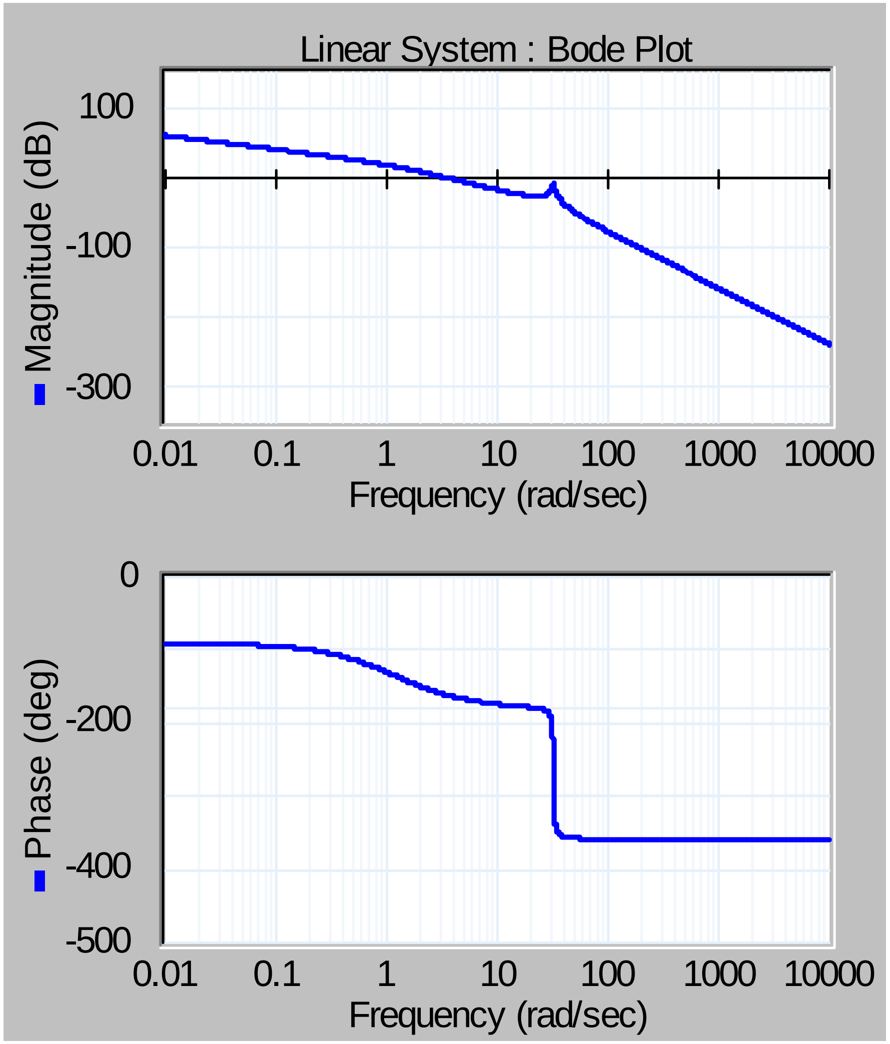
Response to a sweep



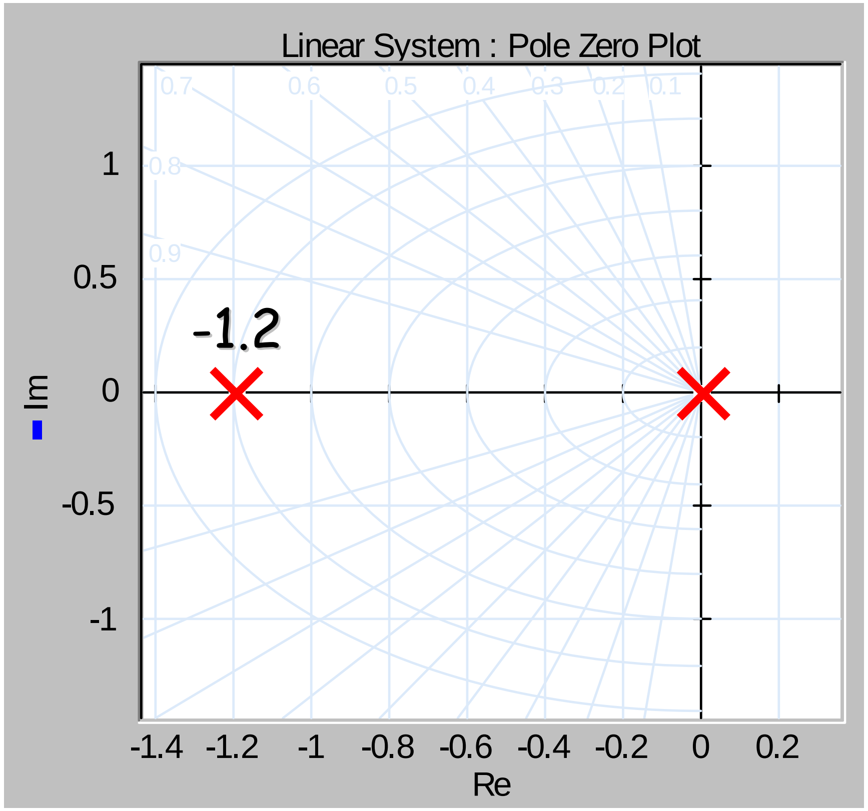
20-sim
demo

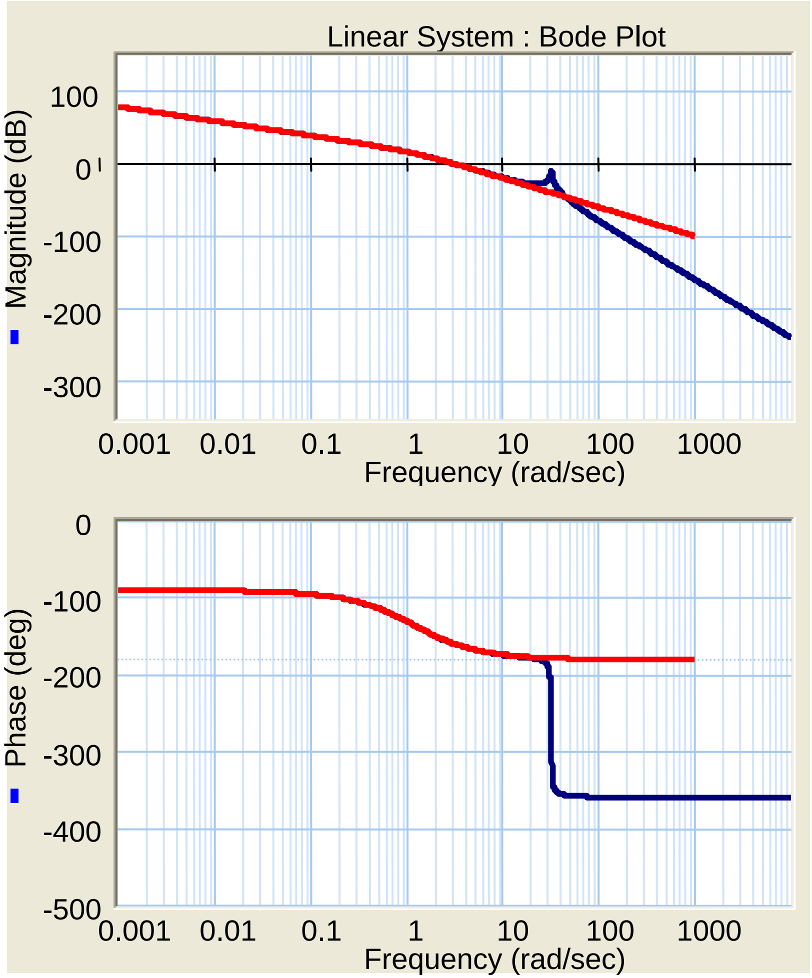
After ‘linearisation’ (current)



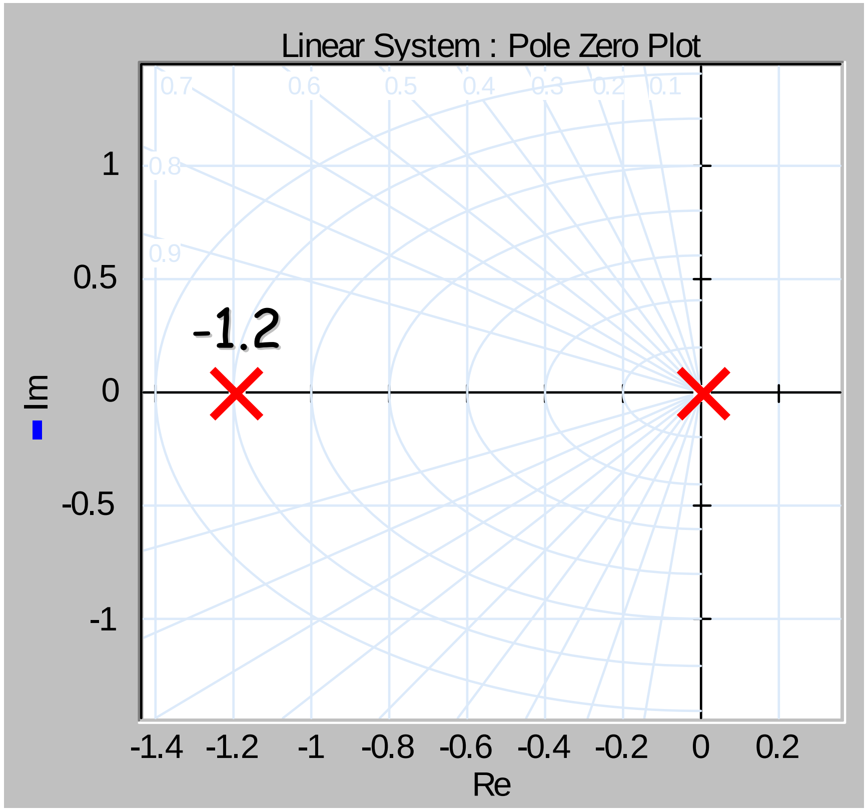


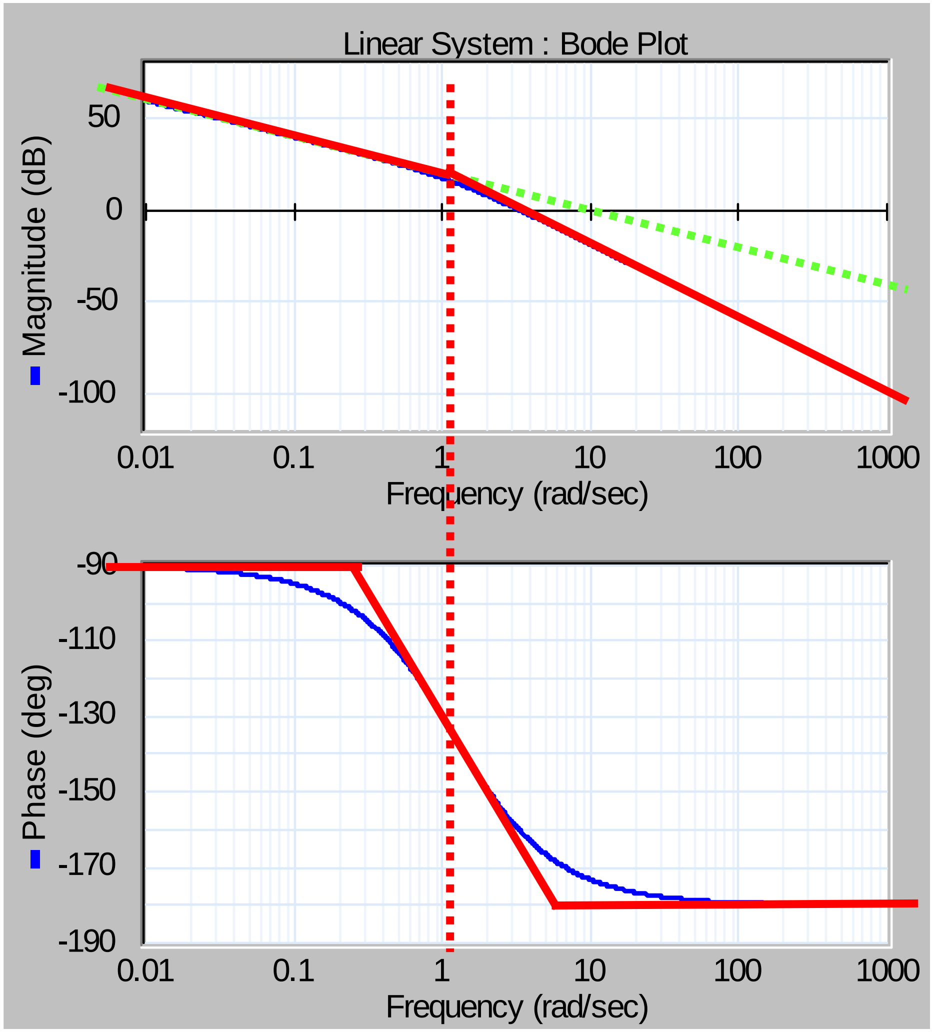
After simplifcation (current)





After simplifcation (current)



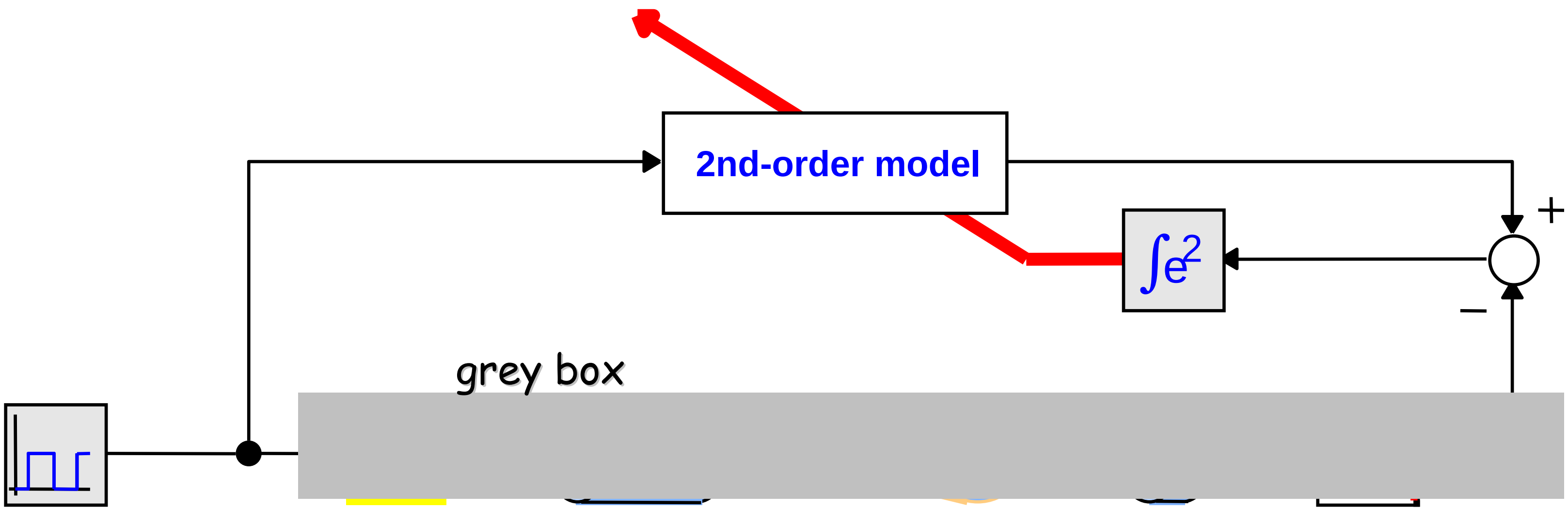


Black (grey) box modelling

- Starts with measurements of an existing system
- Fits a (simple) dynamic model through the response

Identification (current)

Control Engineering
University of Twente

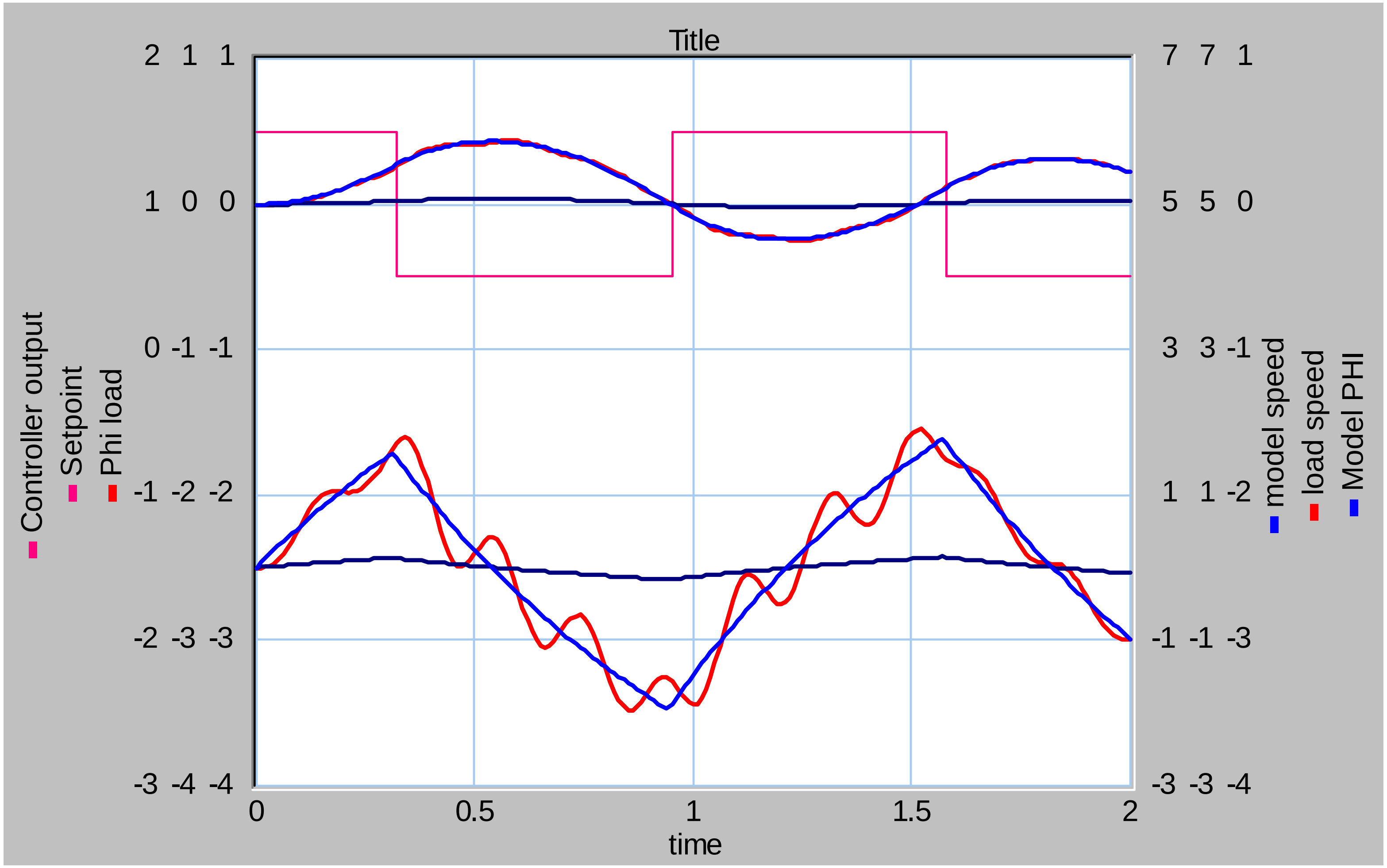


This model demonstrates how a 4th-order system can be approximated by a 2nd-order system

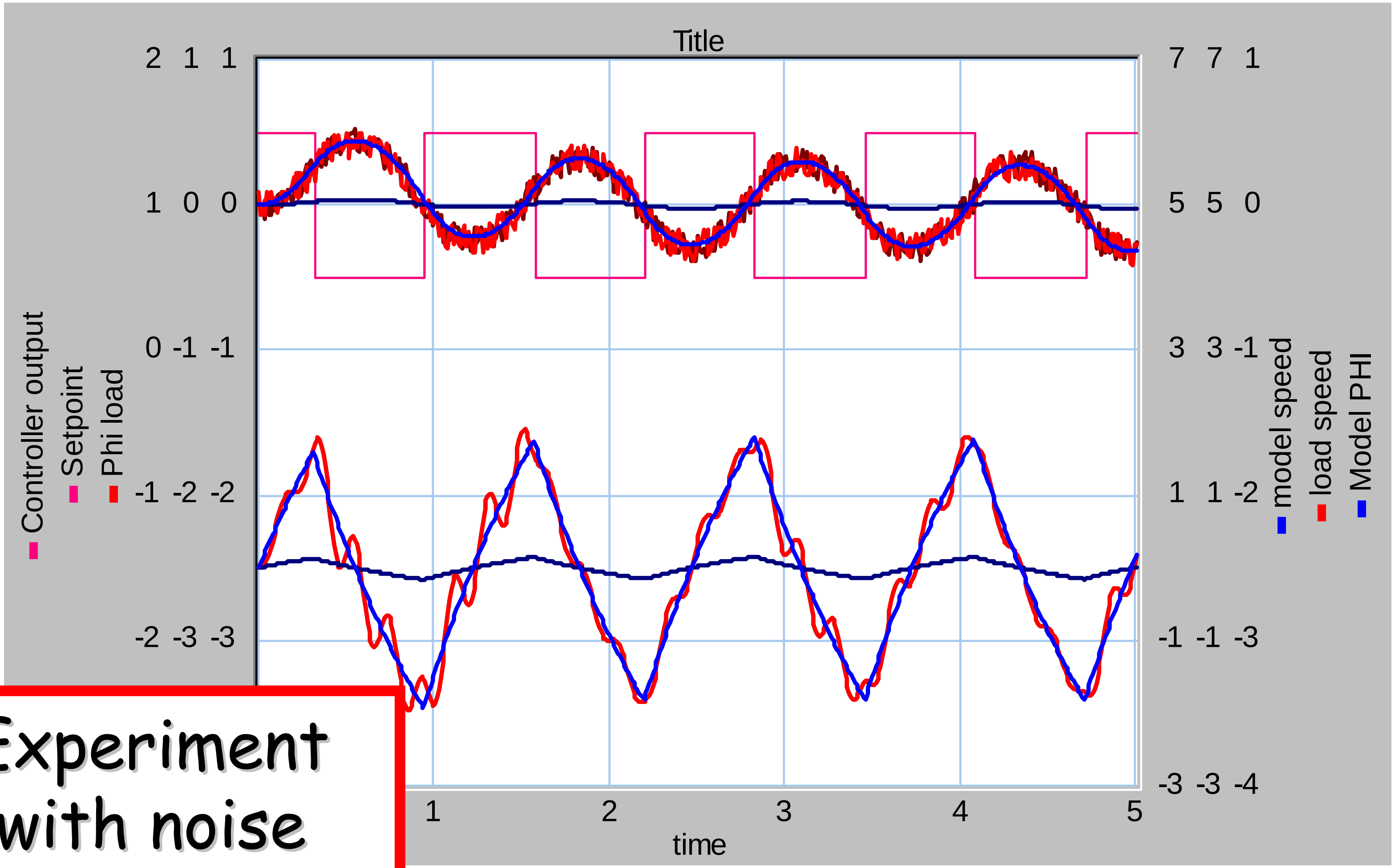
Run the experiment for identification

20-sim

Hill climbing

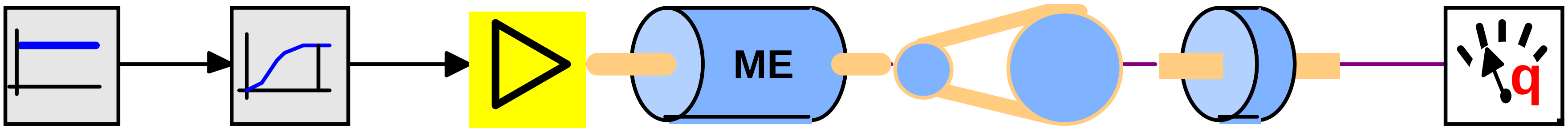


Hill climbing (noise)



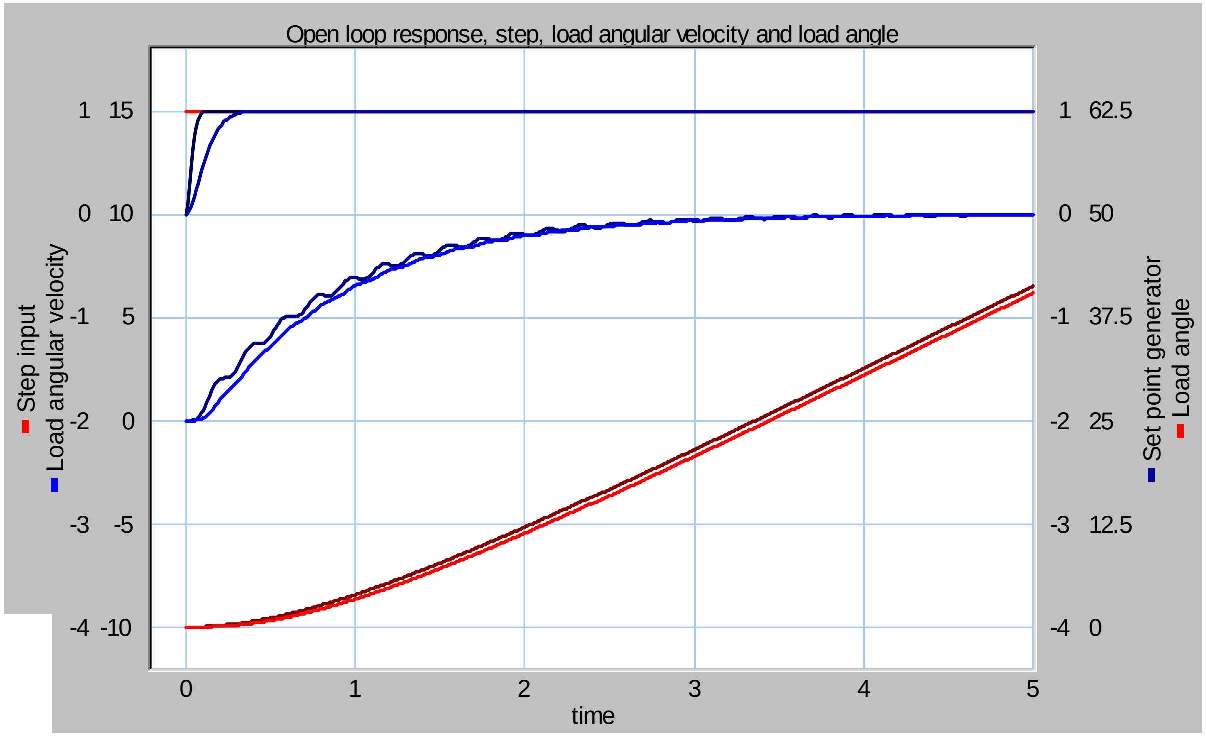
Experiment with noise

LF behaviour



$\omega = 50$

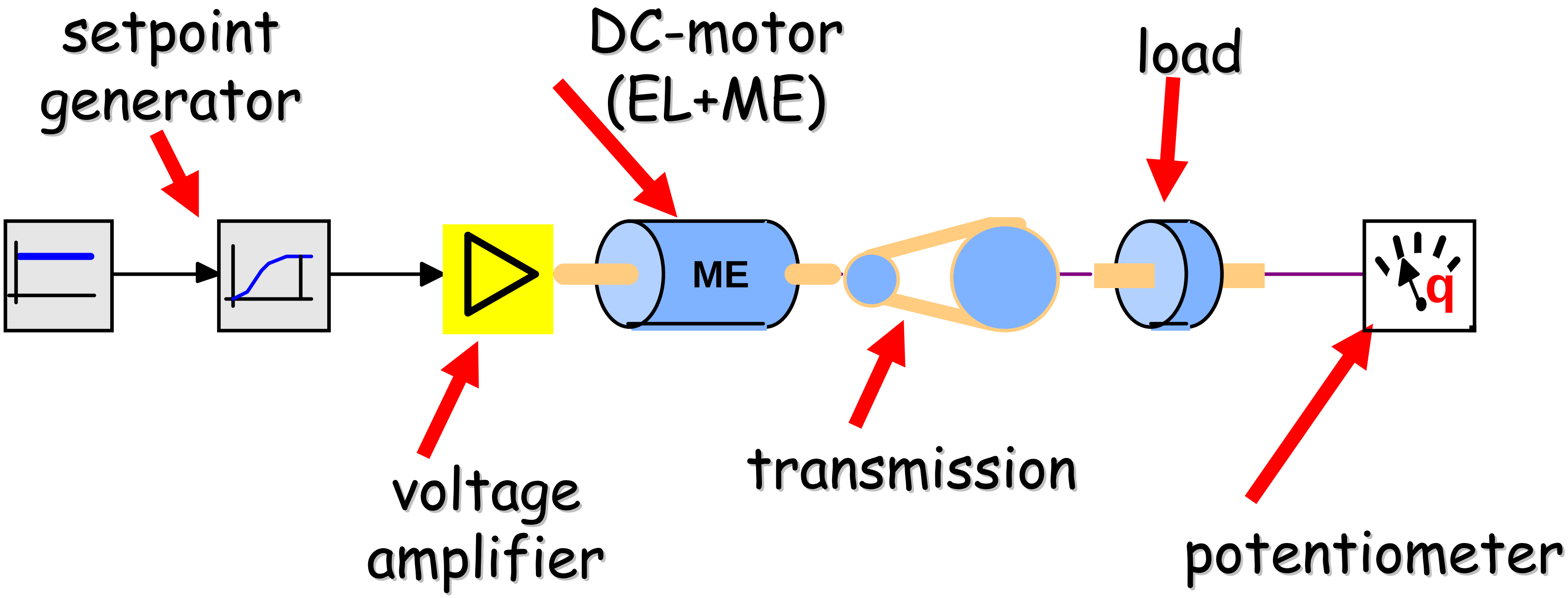
$\omega = 15$



demo

20-sim

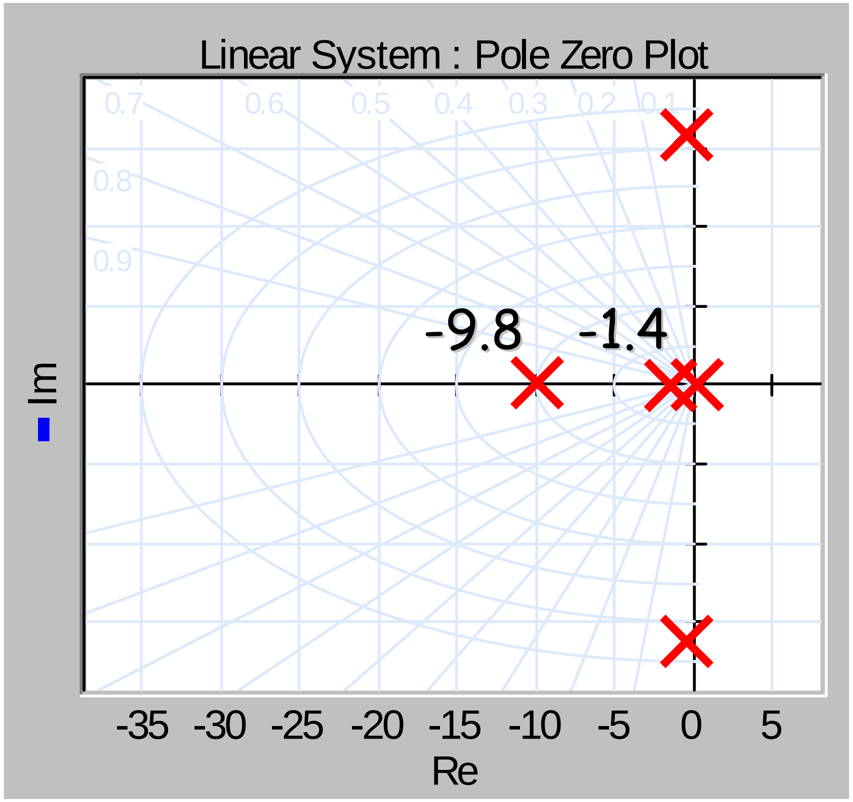
Demo process (volt)

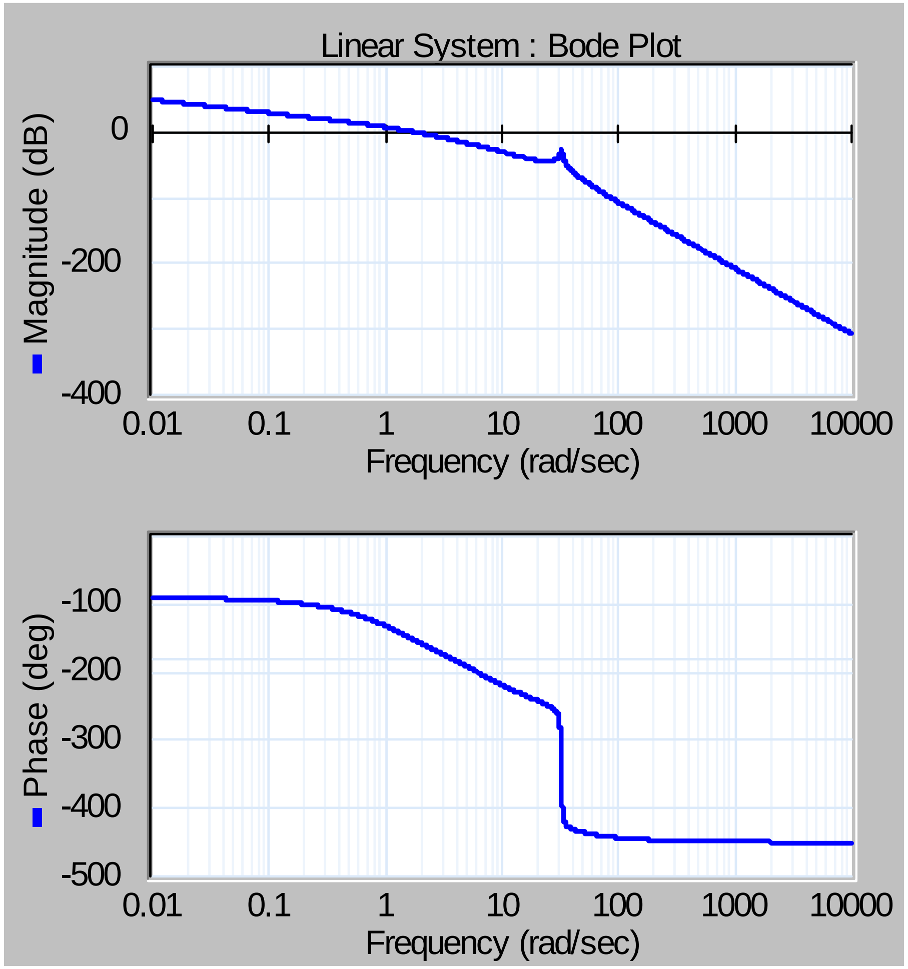


Demo

20-sim

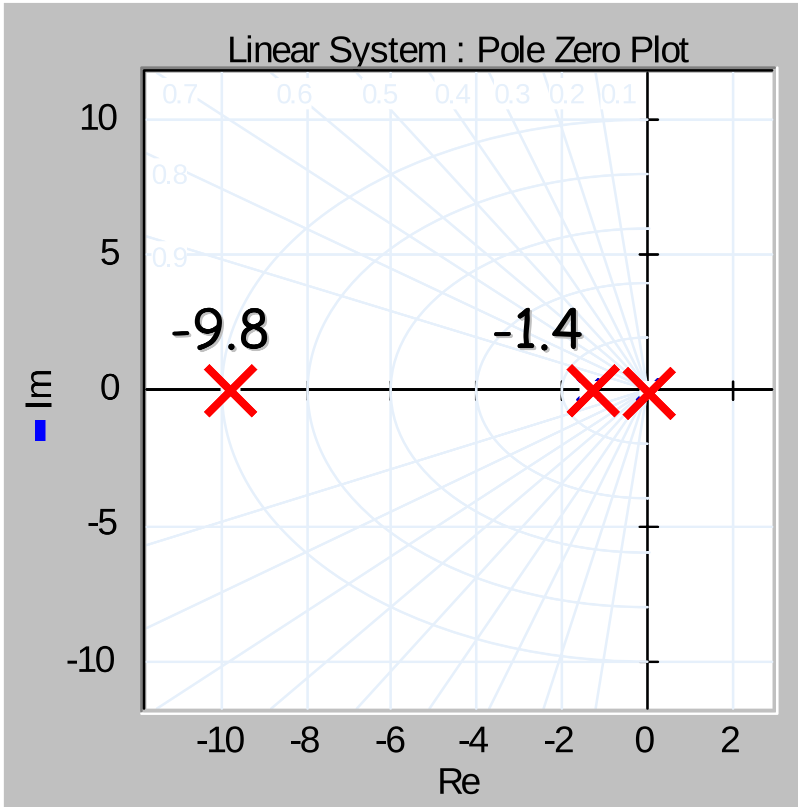
After 'linearisation' (volt.)

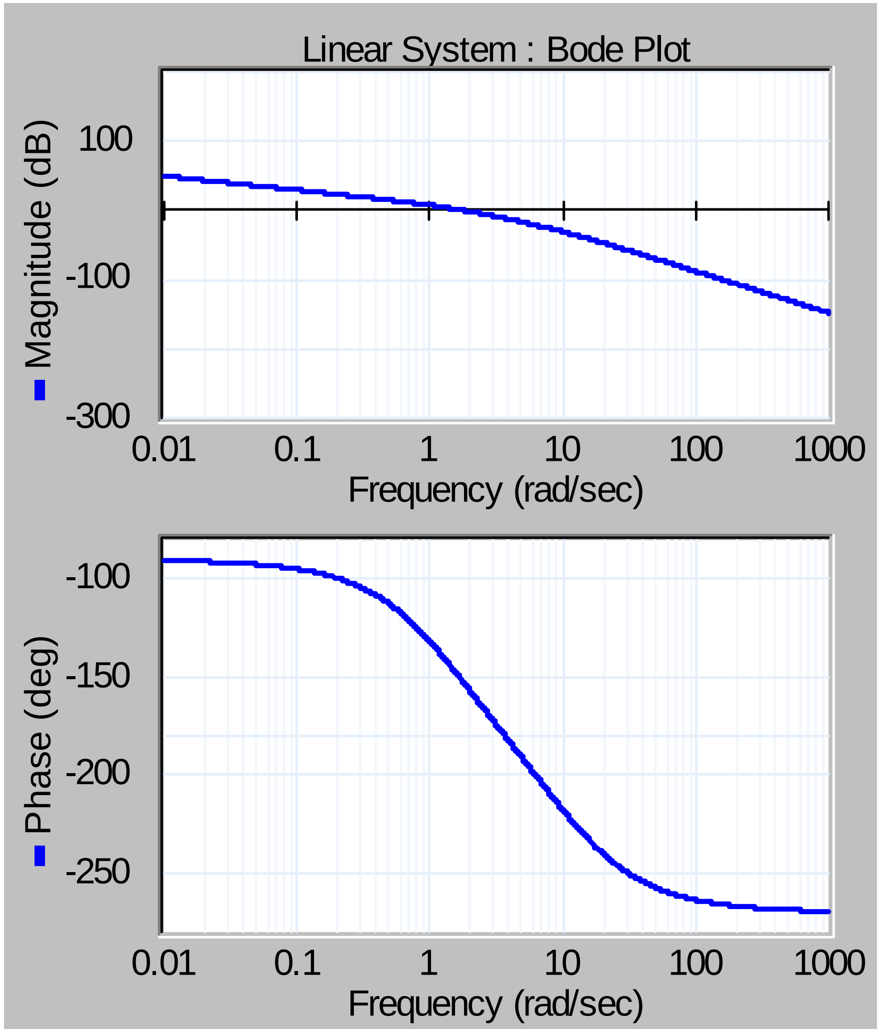




After simplification (volt.)

Control Engineering
University of Twente

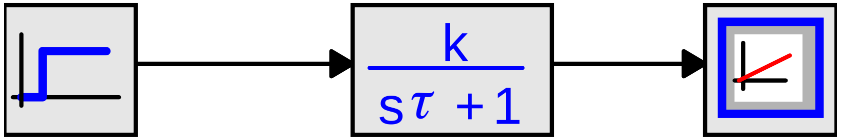


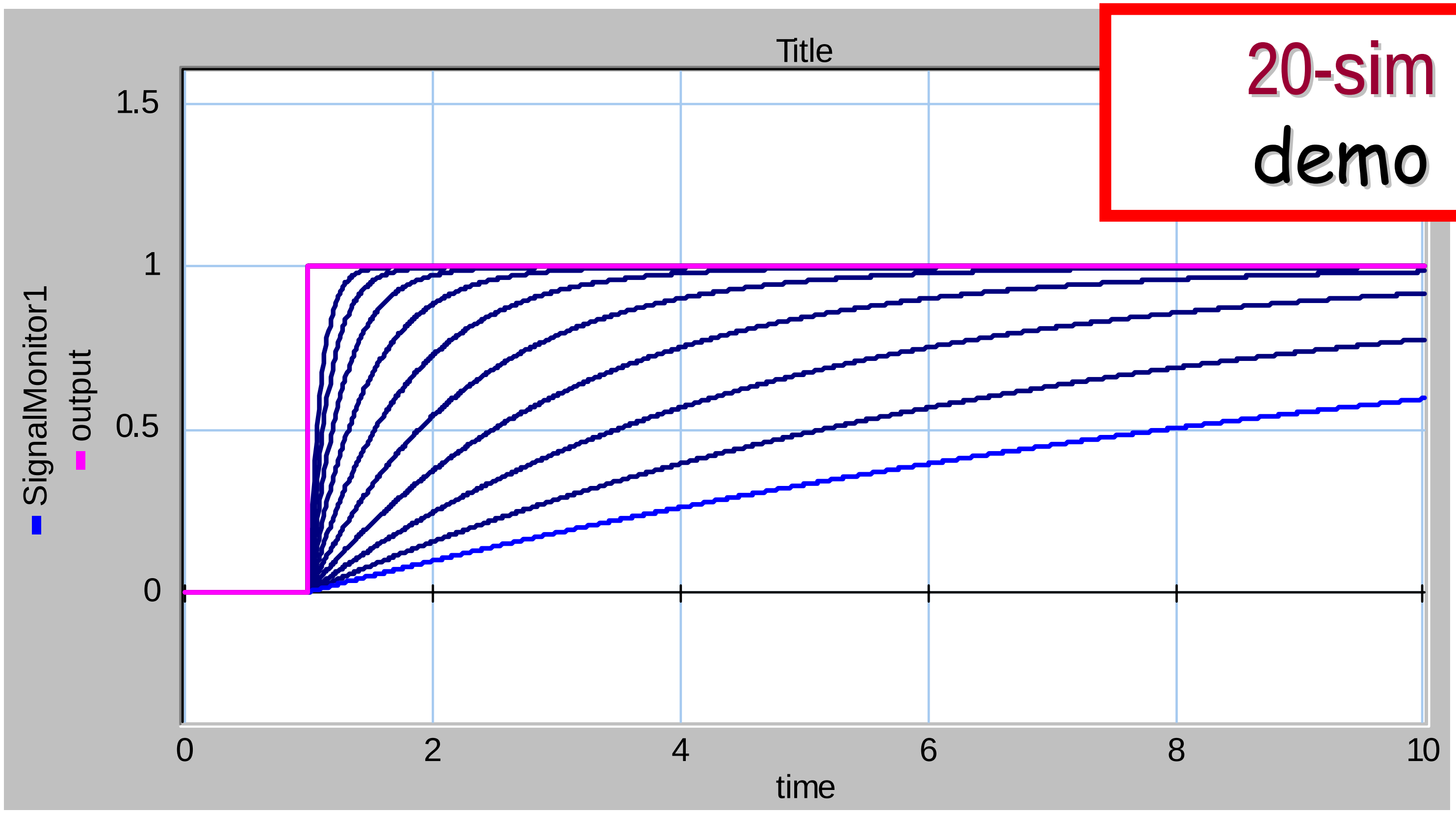


Relation s-domain
↔
time domain

First-order system

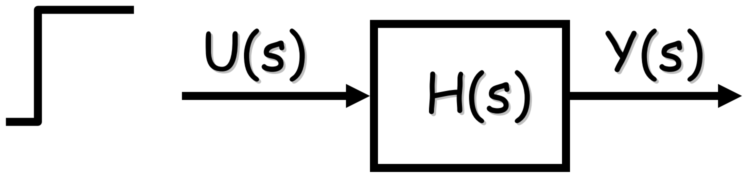
0.1 <tau <10





20-sim
demo

Solving the Differential Eq.



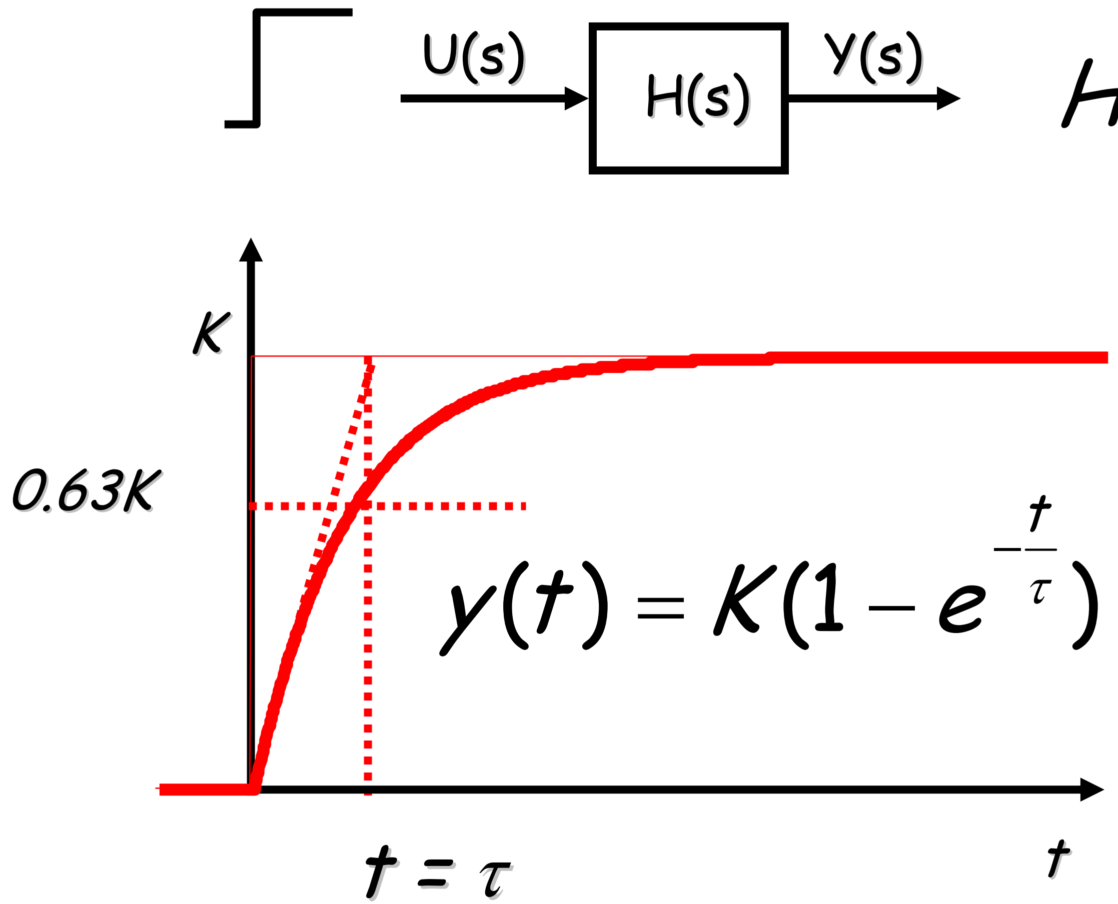
$$H(s) = \frac{K}{s\tau + 1}$$

$$Y(s) = H(s)\frac{1}{s} = \frac{K}{s(s\tau + 1)}$$

$$= \frac{Ka}{s(s+a)} = K\left(\frac{1}{s} - \frac{1}{s+a}\right)$$

$$\rightarrow y(t) = K(1 - e^{-at}) = K(1 - e^{-\frac{t}{\tau}})$$

Solving the Differential Eq.



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

$$y(t) = K(1 - e^{-\frac{t}{\tau}})$$

$$e^{-1} = 0.37$$

representations

system gain

root locus gain

$$\frac{K}{s\tau+1} = \frac{K/\tau}{s+1/\tau} = \frac{Ka}{s+a} = \frac{K'}{s+a}$$

lowest power
of s = 1

highest power
of s = 1

A polynomium with
the highest power
of s = 1, is called
a monic polynomium

representations (2)

system gain

root locus gain

$$\frac{K}{s(s\tau+1)} = \frac{K/\tau}{s(s+1/\tau)} = \frac{Ka}{s(s+a)} = \frac{K'}{s^2+as}$$

lowest power
of s = 1

highest power
of s = 1

DC-gain versus system gain

$$\frac{K}{s\tau + 1}$$

system gain = K

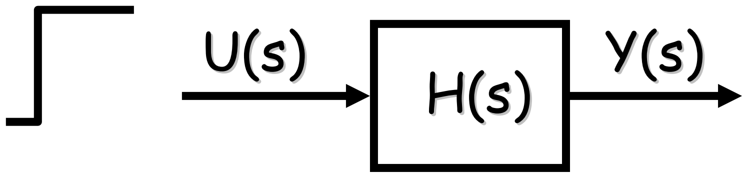
DC-gain = K

$$\frac{K}{s(s\tau + 1)}$$

system gain = K

DC-gain = ∞

Final value theorems



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

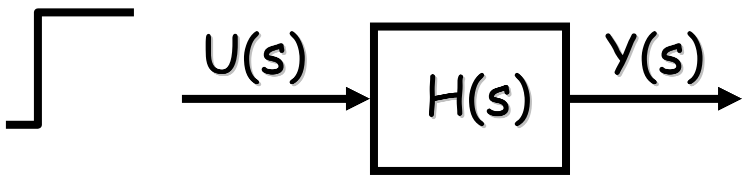
$$Y(s)=H(s)\frac{1}{s}$$

$$\lim_{t\to\infty} y(t)=\lim_{s\to 0} sY(s)=\lim_{s\to 0} H(s)=$$

$$\lim_{s\to 0}\frac{K}{s\tau+1}=K$$

final value theorem

Initial value theorems



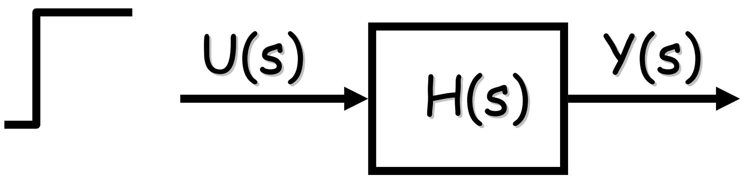
$$H(s) = \frac{K}{s\tau + 1}$$

$$\lim_{t \to 0} y(t) = \lim_{s \to \infty} sY(s) = \lim_{s \to \infty} \frac{K}{s\tau + 1} = 0$$

initial value theorem

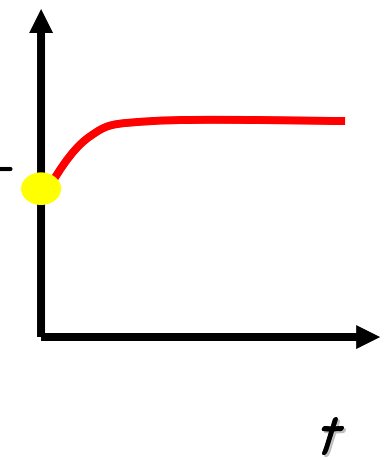
$$\lim_{t \to 0} \frac{d}{dt}\left(y(t)\right) = \lim_{s \to \infty} s\left(sY(s)\right) = \lim_{s \to \infty} \frac{Ks}{s\tau + 1} = \frac{K}{\tau}$$

First-order plus zero



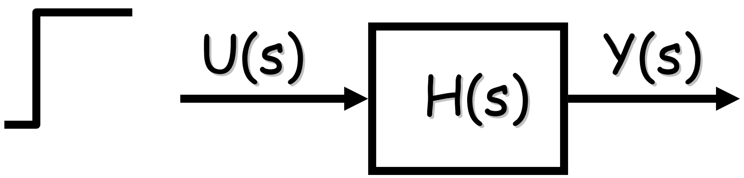
$$H(s) = K\frac{s\tau_2 + 1}{s\tau_1 + 1}$$

$$\lim_{t \to 0} y(t) = \lim_{s \to \infty} sY(s) = K\frac{s\tau_2 + 1}{s\tau_1 + 1} = K\frac{\tau_2}{\tau_1}$$



$$\lim_{t \to \infty} y(t) = \lim_{s \to 0} sY(s) = K\frac{s\tau_2 + 1}{s\tau_1 + 1} = K$$

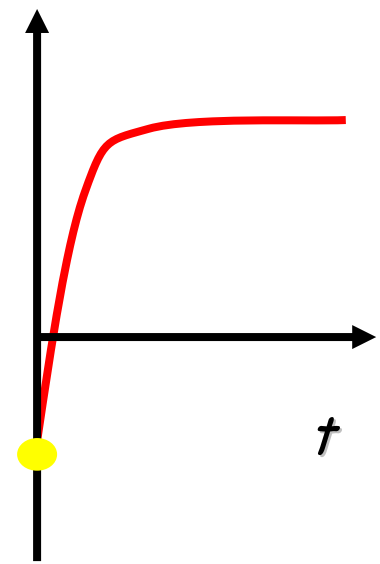
First-order plus zero



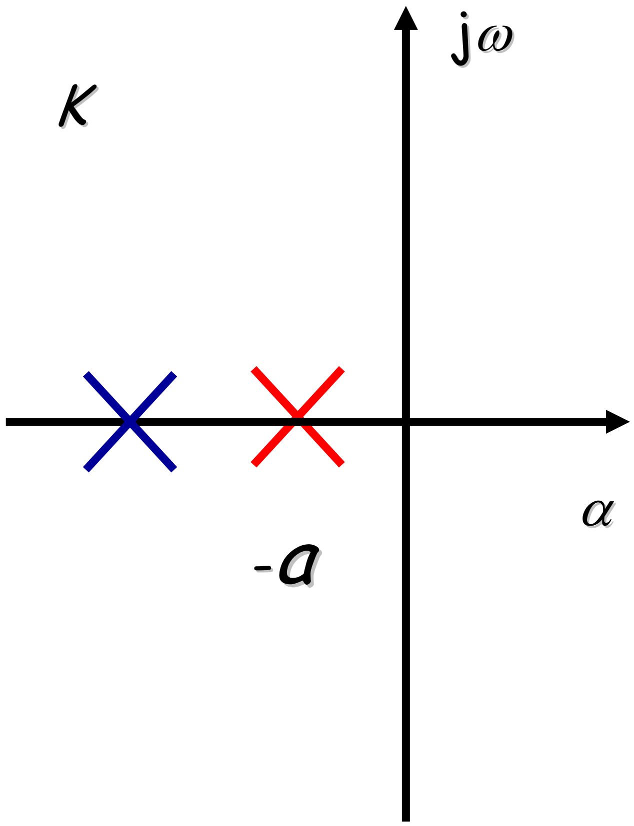
$$H(s) = K\frac{-s\tau_2 + 1}{s\tau_1 + 1}$$

$$\lim_{t\to 0} y(t) = \lim_{s\to\infty} sY(s) = K\frac{-s\tau_2 + 1}{s\tau_1 + 1} = -K\frac{\tau_2}{\tau_1}$$

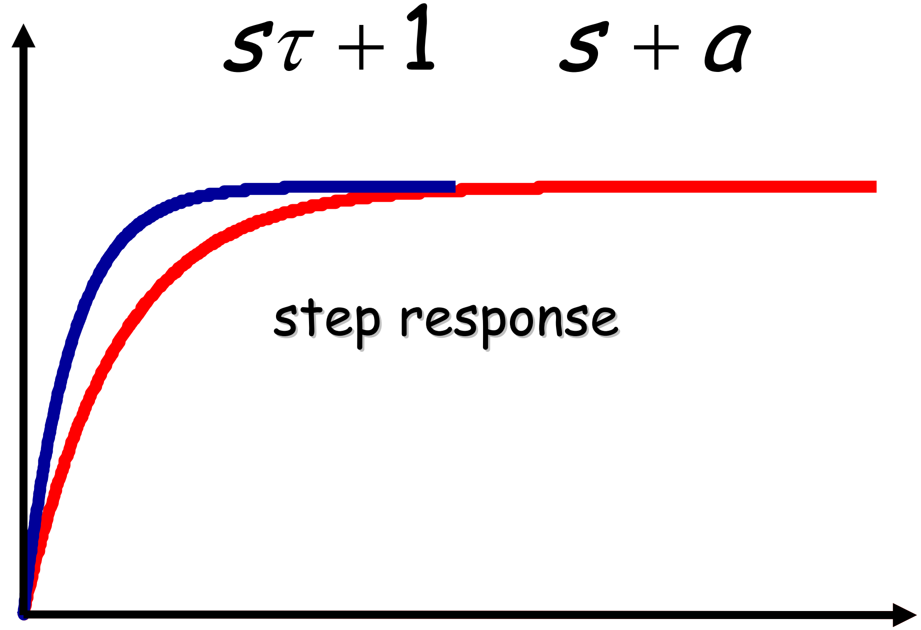
$$\lim_{t\to\infty} y(t) = \lim_{s\to 0} sY(s) = K\frac{-s\tau_2 + 1}{s\tau_1 + 1} = K$$



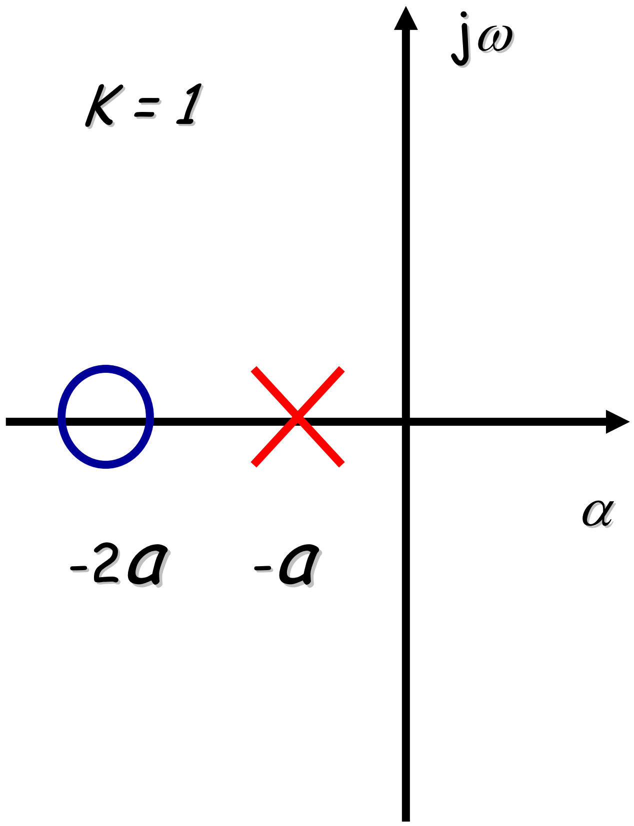
s-plane ←→ time

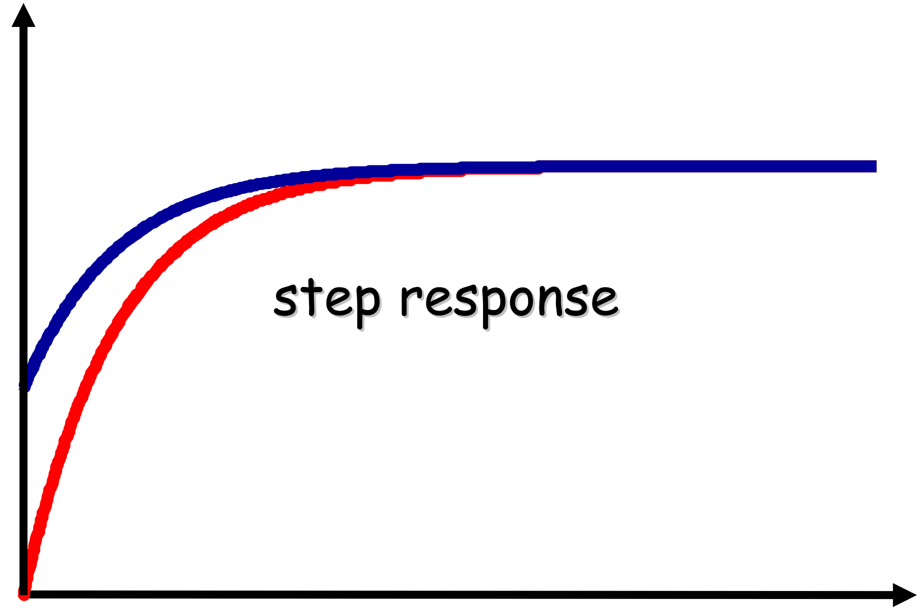


$$\frac{K}{s\tau+1}=\frac{K'}{s+a}$$

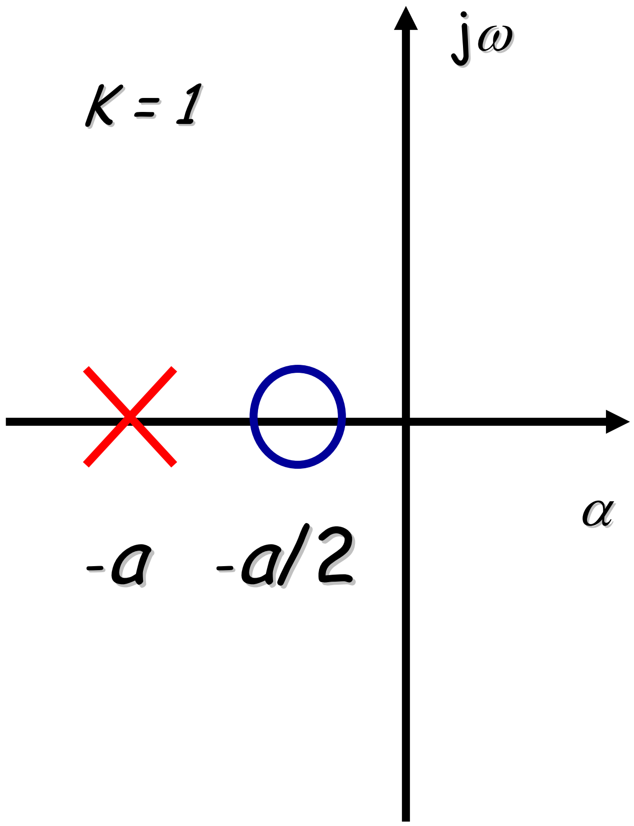


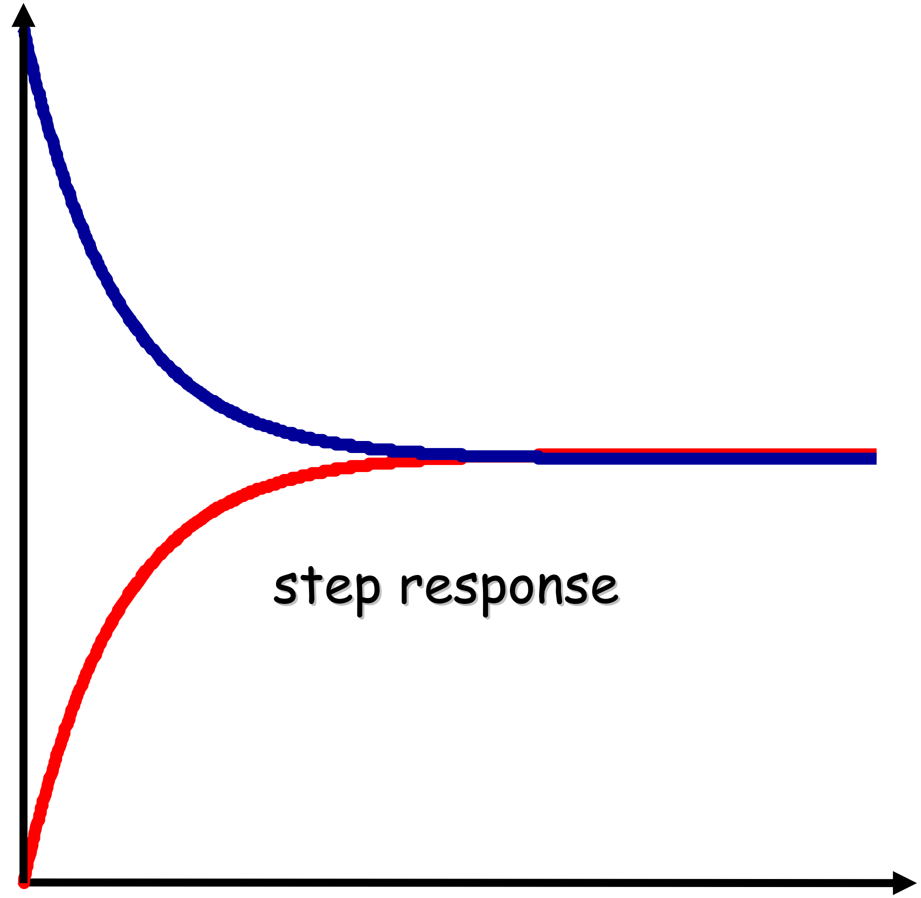
s-plane ←→ time



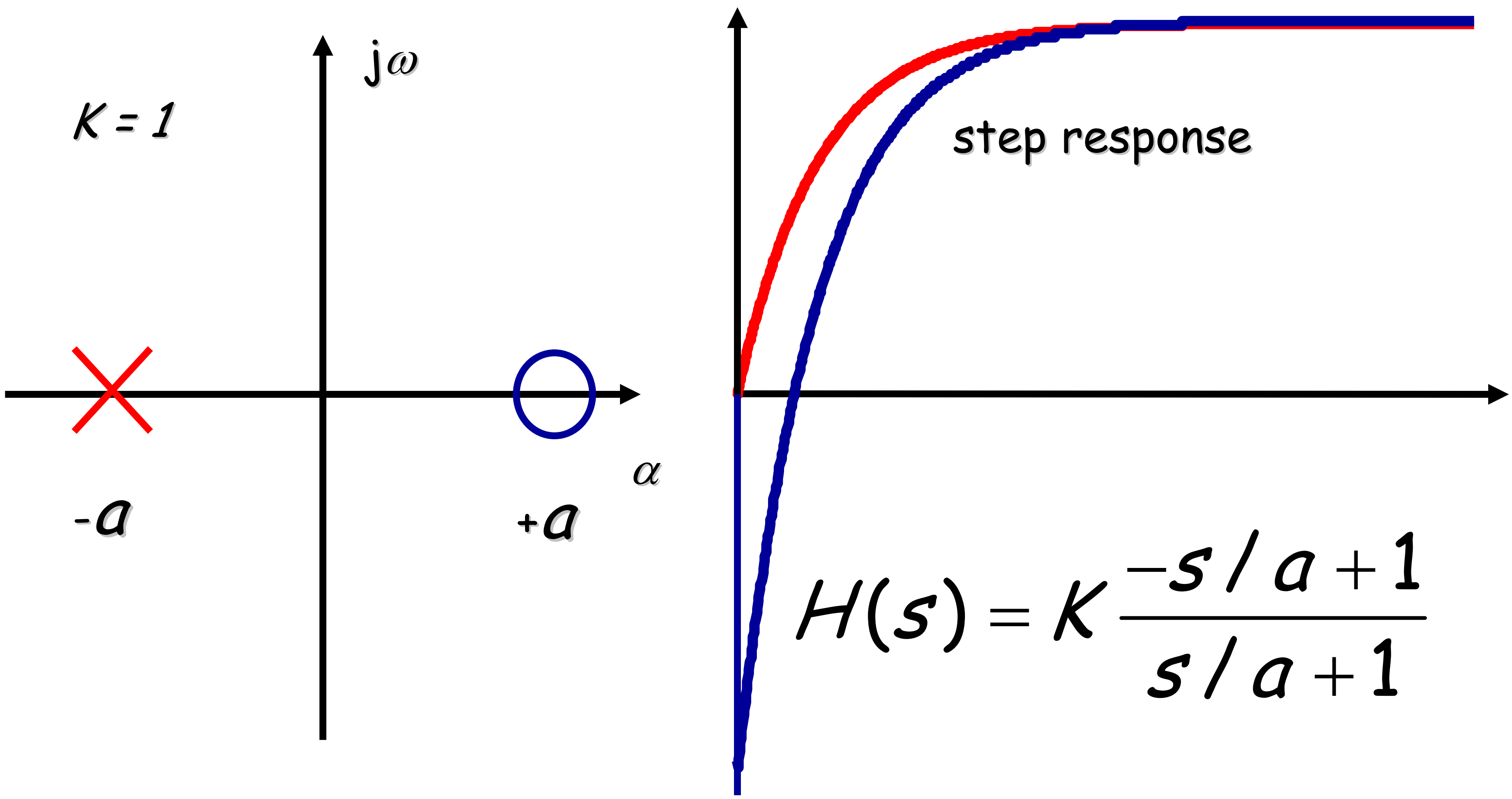


s-plane ←→ time



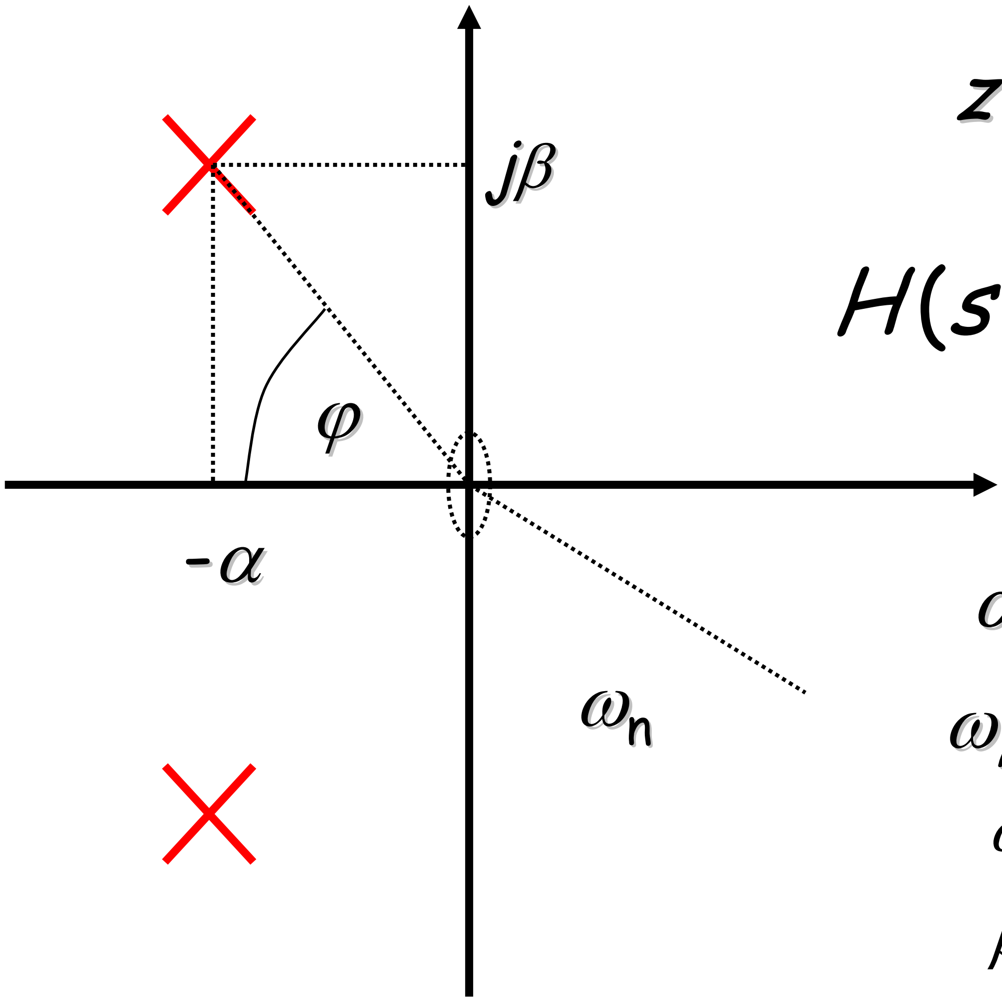


s-plane ←→ time



$$H(s) = K\frac{-s/a+1}{s/a+1}$$

Second-order system



$z = \cos\varphi$ damping ratio

$$H(s) = \frac{\omega_n^2}{s^2 + 2z\omega_n s + \omega_n^2}$$

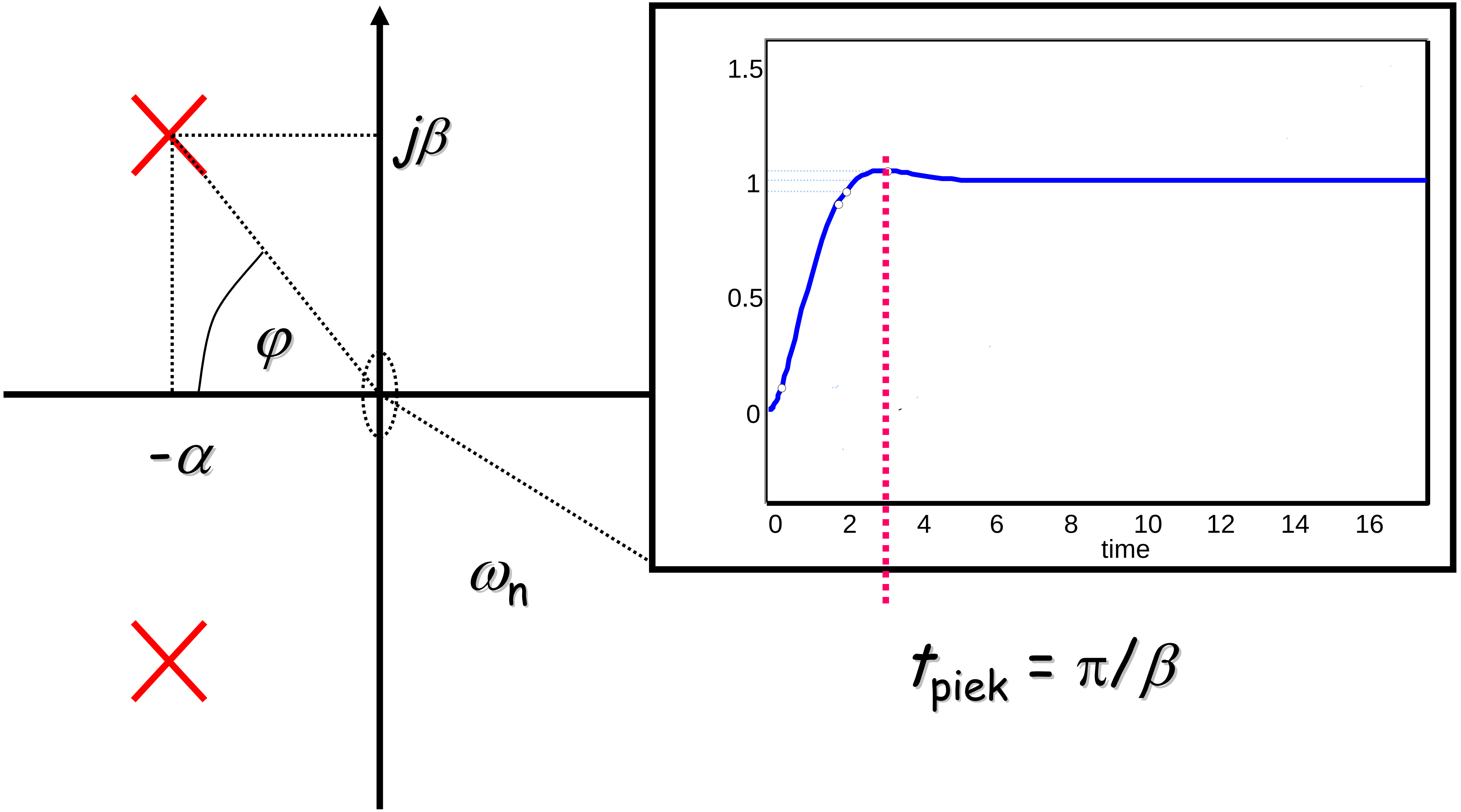
α = absolute damping

ω_n = natural frequency

$$\alpha = \omega_n \cos(\varphi) = \omega_n z$$

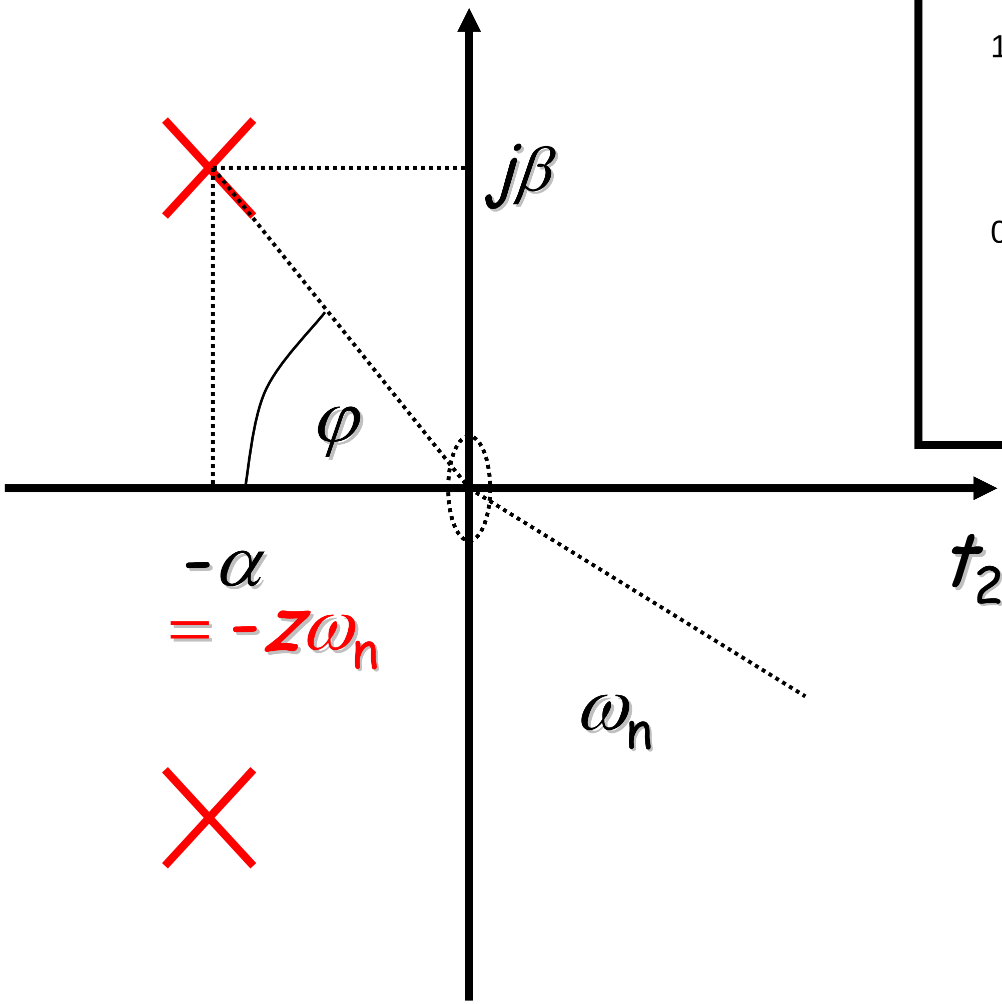
$$\beta = \omega_n \sin(\varphi)$$

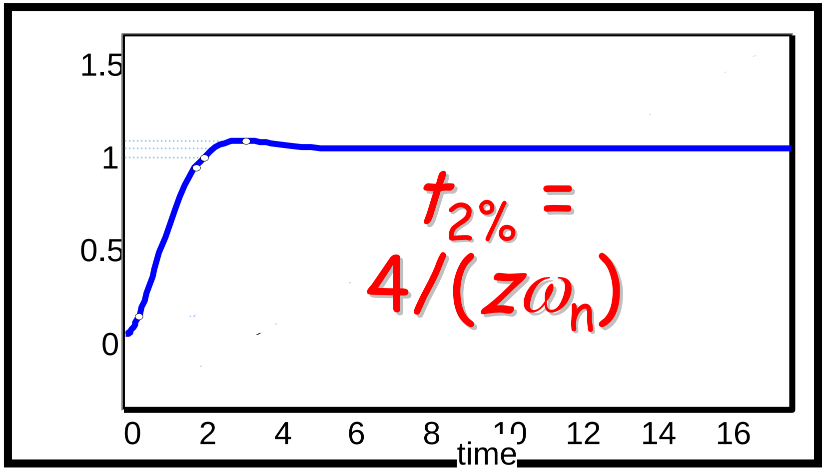
Second-order system



$t_{piek} = \pi / \beta$

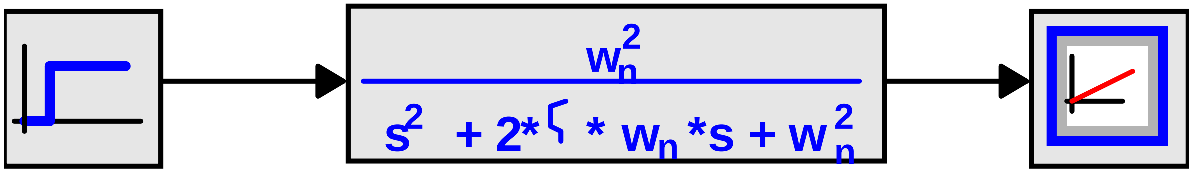
Second-order system

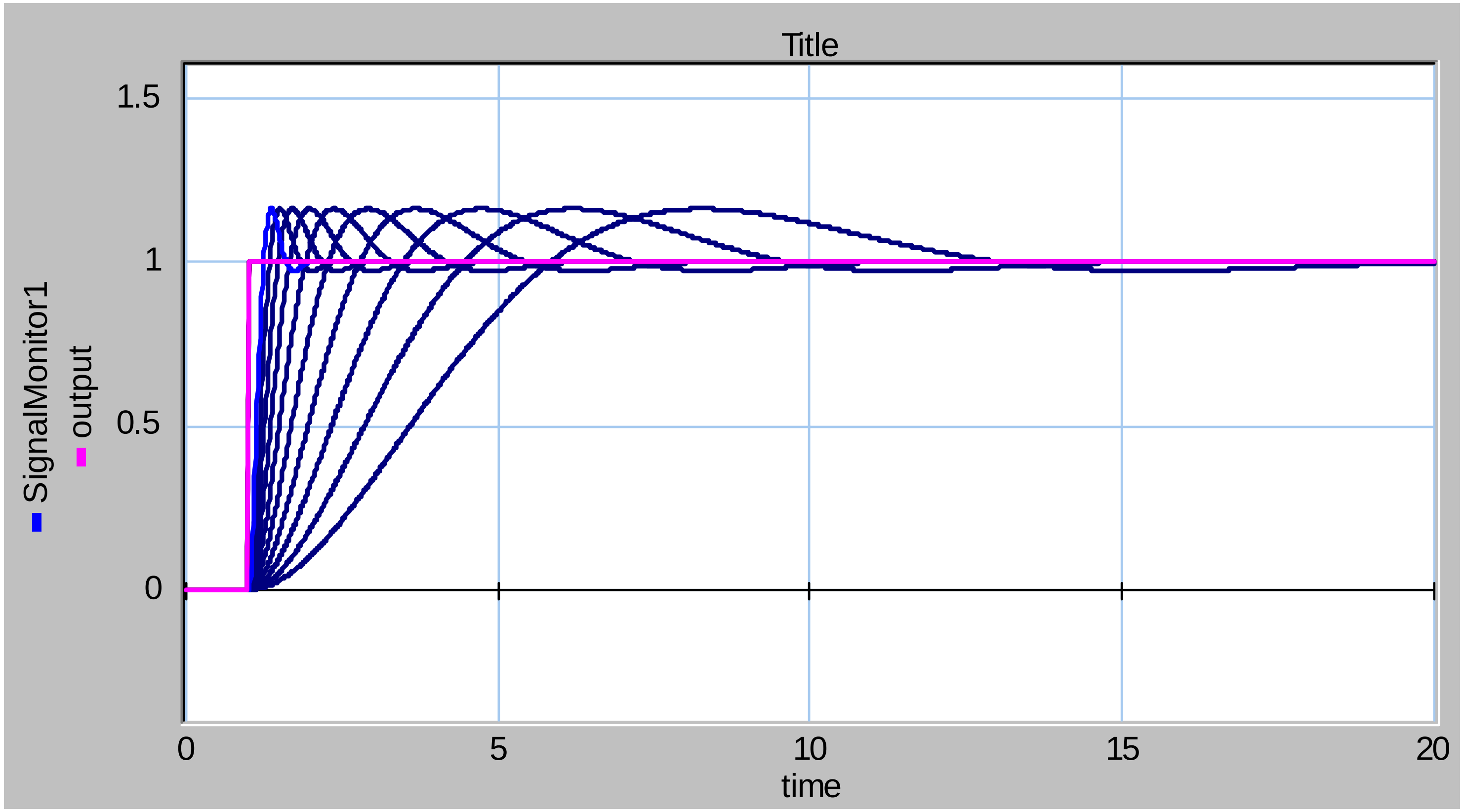




$t_{2\%}$ = time where response remains within 2% of final value

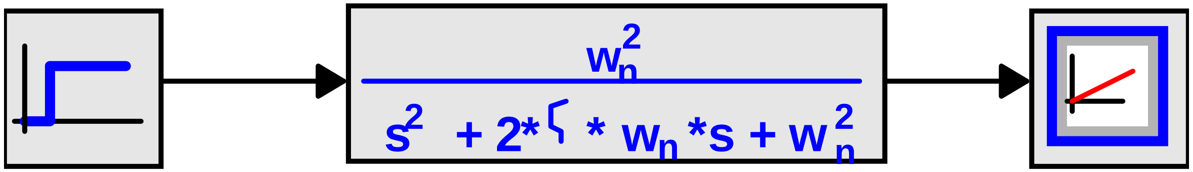
Second-order system

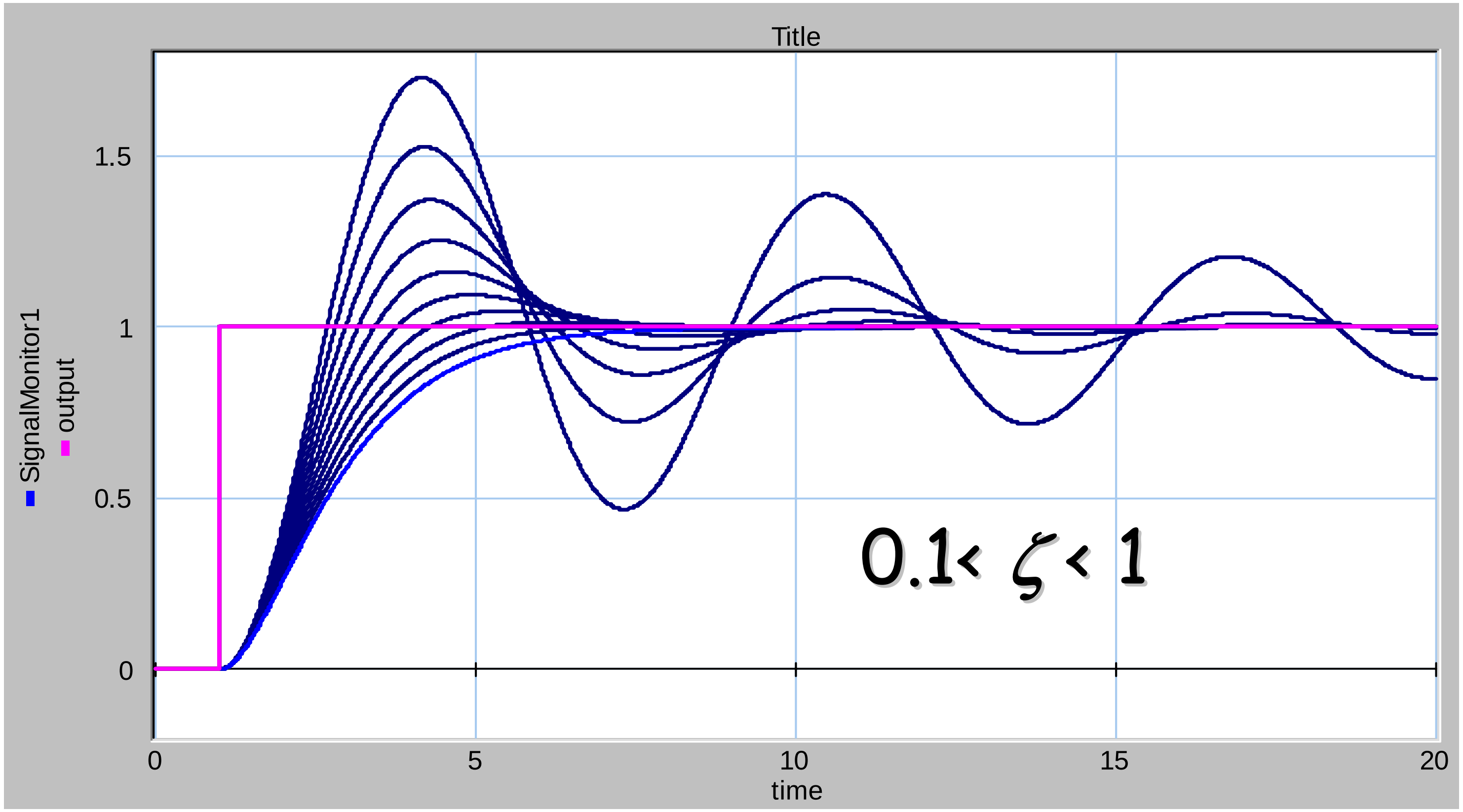




Second-order system

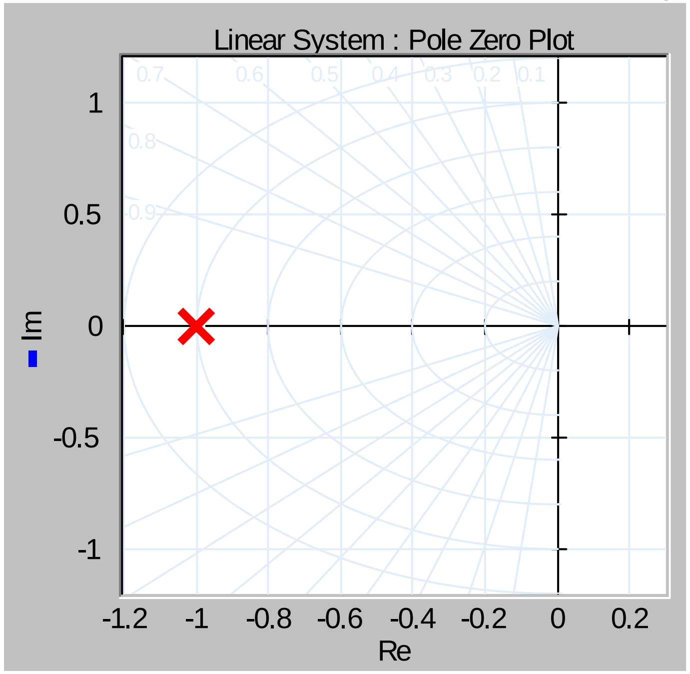
Control Engineering
University of Twente

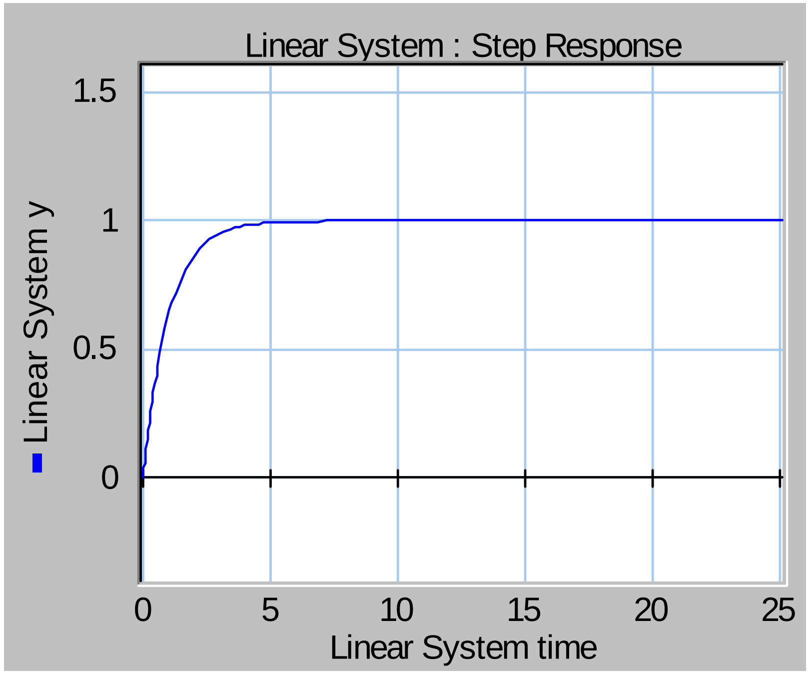




Exercise (1)

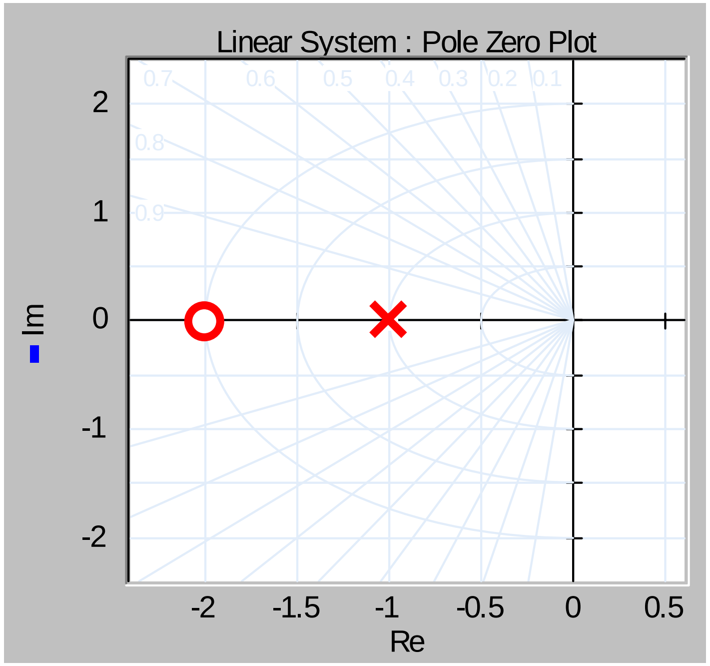
Use the linear systems editor of 20-sim to simulate a first-order system and investigate the influence of a varying gain and time constant on the step response

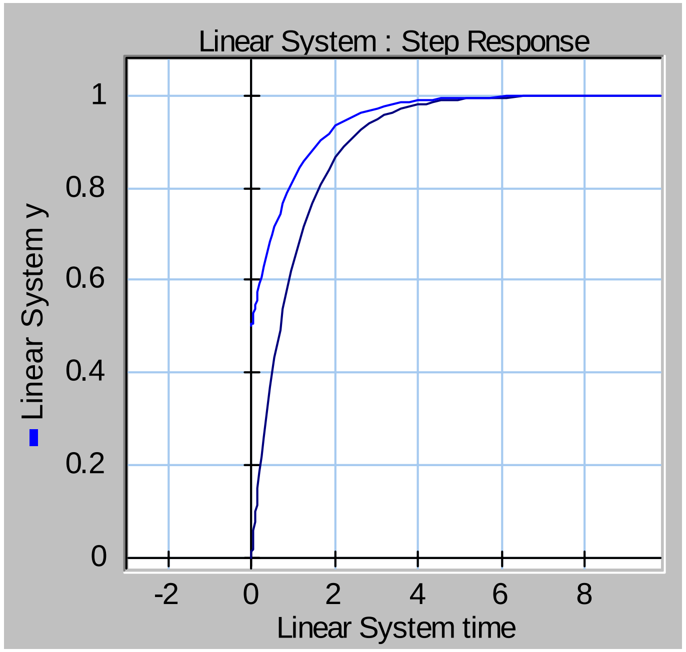




Exercise (2)

Do the same for a first-order system with a zero and investigate the influence of a varying zero on the step response

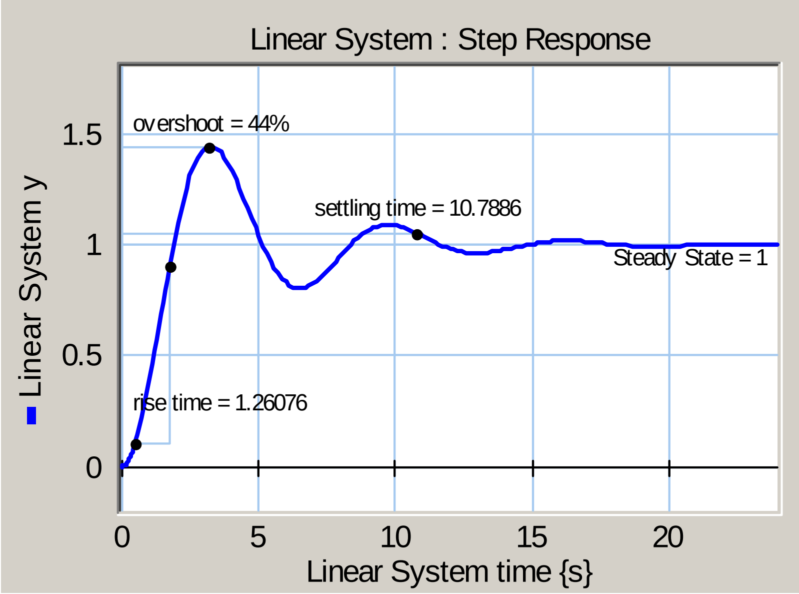


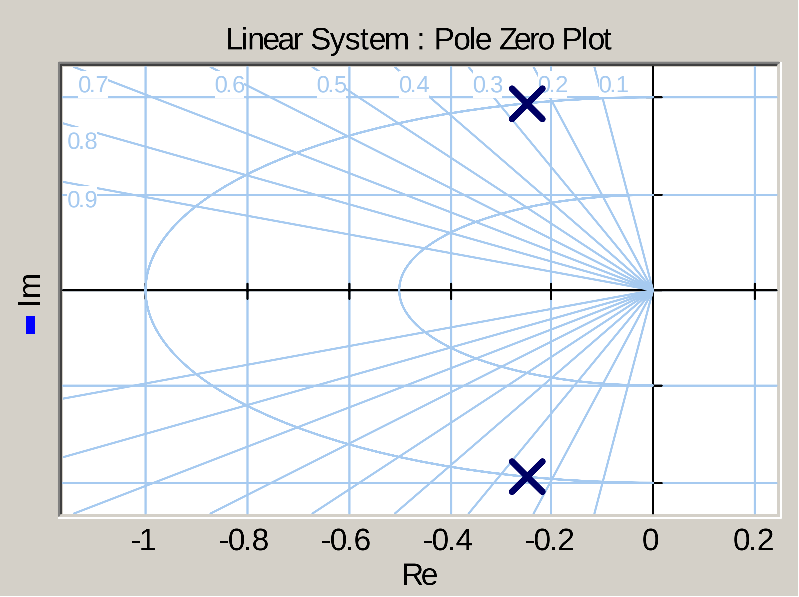


Exercise (3)

Investigate the influence of varying ω_n en z for a second-order system on the step response.

Investigate the effect of an extra pole or zero





Exercise (4)

Check the relation between peak time and settling time and the location of the poles of a second order system.

Generate the responses with 20-sim

